COMPUTERS AND LEARNING: DO THEY WORK?
A REVIEW OF RESEARCH

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INTRODUCTION

Computers in the classroom represent a tremendous investment of time, energy and money. But do they work? Are they worth it? Do children learn better or more by having access to a computer? Not surprisingly, the answers to these questions are not simple yes or no responses. The most accurate statement to characterize what we do know is, "It depends." It depends on what type of child is using the computer in which sort of way, under which conditions, for what duration and at what intervals.

To be more precise, the question is not, "Do computers work?" or "Do computers improve learning?" but rather, "How can the unique qualities of the computer be harnessed to enhance instruction in ways that are not available without a computer?"

What are these unique features of the computer that can enhance learning? Linn and Fisher describe key features of the computer learning environment that distinguish it from non-computer environments.[1] First, the computer is interactive. There is a cyclical process of providing information to and receiving immediate feedback from the computer. This interactive quality can turn an encounter with the computer into a dynamic interchange, providing a constant incentive to press on. Next, the computer is precise. In order to get the computer to perform the desired operations, the learner must be specific and precise in his or her instructions or responses. Third, the computer can be consistent. The instruction and feedback provided in a single program can be the same for each and every student who interacts with that program.* The feedback is consistent regardless of appearance, sex, weight, ethnicity or ability. In addition, the feedback that a student receives is private. Not only do children not risk public criticism and embarrasment with a response, but they have multiple chances to try and try again. Another feature is the computer's ability to provide multiple and dynamic representations of a concept or phenomenon, representations that show interrelationships among concepts, and that can change as the phenomena change.

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*Intelligent tutoring systems are designed to provide responses that are tailored to the indivisual student's performance or response, and thus do not provide the consistency of response available in some of the simpler computer-assisted instructional programs.

1. Marcia C. Linn and Charles W. Fisher, "The Gap Between Promise and Reality in Computer Education: Planning a Response," Paper presented at Conference for California Educators, San Francisco, CA, 1983.

And finally, the functions a computer can perform are multiple -- we have only begun to tap into their potential for learning. Throughout the remainder of this section you will read about a wide range of clever and creative ways that researchers and developers have elected to enhance learning. It is precisely this multi-faceted, multi-functional potential of the computer that makes simple answers to the question, "Are computers effective in the classroom?" so elusive.

The Changing Goals of Education

To complicate matters, the introduction of computers into the classroom has exacerbated pedagogical dilemmas that have plagued society for decades. Questions such as "What should students learn?", "How should they learn?", "What is the role of teachers in that learning process?", and "How should schools be structured to facilitate learning?", are all at issue. These essential aspects of education are more in question now then they have been in over 15 years.

Why are the core ingredients of schooling in question just now? There are several reasons. First, the stage has been set by numerous and highly visible commission reports that have linked economic vitality to the production of a literate and intellectually developed citizenry. Each report has lamented the high incidence of barely literate high school graduates and has stressed the need to develop a society of thinkers and problem solvers. Tucker and Mandel in their essay on "Competitiveness and the Quality of the American Workforce,"[2] articulate what we expect of those who exit our system of schooling. "The standard should demand that prospective employees show that they can think on their feet, speak and write well, exercise sound judment in complicated situations, and draw on a thorough understanding of mathematics, science, and other subjects to find a path through a tough problem when there is no single right solution."

A variety of national and international assessment results support the claim that student performance on higher, more analytical types of thinking have declined. For example, when the National Academy of Science analyzed the results of the 1983 National Mathematics Assessment, they reported, "It is disappointing to find no improvement in applications items -- on those items that call for a deeper understanding of principles -- nor in the problem solving that is more realistic precisely because it is nonroutine."[3]

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2. Marc Tucker and David Mandel, Competitiveness and the Quality of the American Workforce (Washington, DC: Carnegie Forum for Education and the Economy, 1987).

3. Janet Raloff, "National Mathematics Test Results Reflect No Real Gain in Ability, Analyses Show," Science News, as reported in the Los Angeles Times, June 1983.

Recent international comparisons reveal that the science achievement of U.S. students has improved little over the past two decades, and lags far behind that of students in other countries. Even the top ten percent of our science students are outperformed by students in England, Japan and six other countries .[4]

These findings are not surprising. Over the past 25 years, our national priorities have been focused on achieving equity in society through equity in education. Federal funds have been directed at bringing the neglected into the mainstream. This has meant working on the basics -- laying the foundation for more advanced levels of learning. Results show that educators have actually done quite well at this. There have been consistent gains in student performance in the basic skills.[5]

But now it's time to move on -- to advance up the intellectual ladder. The problem is that this new agenda requires profound changes in how we conceptualize learning and how we structure the learning environment. Such changes will be particularly difficult to achieve because understanding and promoting higher levels of thinking are complex and subtle, and because almost everything in our current educational structure works against thoughtful and deep learning. Our tests reinforce shallow learning and our overburdened curriculum leaves little time for reflection.

In addition, the relatively recent discipline of cognitive science has emerged to shed light on how people think, learn and solve problems. Some of the most exciting and promising advances in theories of learning, and the applications of these theories for use on the computer, come from researchers who study the intricacies of how children learn.

Without question, computers can contribute to learning at all levels -- from mastery of simple addition and subtraction facts, to the understanding and manipulation of the scientific process. They are expanding the range of instructional possibilities far beyond anything imagined a decade ago, and allow the delivery of new forms of instruction that were previously impossible. But their value as tools for accomplishing meaningful intellectual work will never be realized fully without substantial changes in the goals, views and actions of all those who play a role in the educational process.

The Changing Role of Computers

Over the past 25 years, computers have been used in education primarily to provide drill and practice or to convey traditional course content in traditional ways using the computer as the medium of delivery. These uses of the computer

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4. W. J. Jacobson, "Report of the Second International Science Study," Paper presented at the annual meeting of the American Educational Research Association, Wash, DC: 1987.

5. National Assessment of Educational Progress, The Third National Mathematics Assessment: Results, Trends and Issues, 13-MA-01, (Denver, CO: Education Commission of the States, 1983)

had the benefits of releasing the teacher from the drudgery of drill and practice, freeing him or her to work with other students on more complex material, and of motivating students to attend to otherwise boring learning tasks. But, in general, these early uses of the computer did not address the more creative, reflective or meaningful aspects of learning. They poured information in and students served as passive receptacles.

Although there were some early uses of the computer as a tool for the learner, it is only recently that typical computer use has moved beyond programming, computer-assisted instruction, or computer literacy, and into tool uses such as microcomputer-based science laboratories.* Had this study been commissioned two or three years ago, the findings would have been considerably different from what they are today; a study conducted two to three years hence will undoubtedly reflect significant advances from what we see now. The changes are rapid and profound, and at the same time, painstakingly slow and trivial.

We are just now beginning to see software and computer applications that encourage the active construction of knowledge, provide meaningful contexts for learning, promote reflection, foster intellectual work similar to that encountered in adult's work world, and free students from many of the tedious tasks that tend to obfuscate the learning of more complex concepts.

The Changing Role of Teachers

Teachers are central to the effective use of computers in the classroom. While there are some computer applications that can accomplish a learning task independent of the teacher, many are highly dependent upon the way the teacher integrates the computer with appropriate instructional strategies and with existing and emerging curricular and instructional materials. All evidence points to a need for significant changes in the teacher's role in the classroom as computers become more prevalent. It appears that there will be far less need for teachers to provide traditional lectures, and far more need for them to manage students' use of technology in independent and small group inquiry into complex and multi-discipline problems.

The Changing Role of Measurement

Current measurement technology is relatively advanced in assessing whether or not students have learned basic content knowledge, but is still immature in the assessment of more complex thinking skills and the attitudinal or affective outcomes of schooling. It is these types of thinking and problem solving abilities that many computer applications are aimed at enhancing, and without appropriate measures, we can only infer effects. Consequently, the findings that derive from the research reviewed in the following pages is limited to effects that can be measured with the currently inadequate measurement technology. Anecdotal reports suggest that some powerful motivational and learning management outcomes are occurring.

* For a history of computer use in schools, see Beverly Hunter, et al., Learning Alternatives in U.S. Education: Where Student and Computer Meet, Englewood Cliffs, NJ: Educational Technology Publications, 1975

The Research*

There are several approaches to studying the effects of computers in the classroom. Many studies consist of observing how the technology or the software is used by individuals, by small groups of students, or by entire classrooms. Often the intent of this type of research is to improve the software or computer application, or to determine the extent and type of training needed to support teachers in their use of a particular computer application. Other studies of this sort explore the contextual factors that influence how computers are used in schools -- factors such as district support, extent of resources (hardware, software and training), or equity issues.

Cognitive researchers focus on the intellectual processes that are tapped by the computer. The focus of study is often the individual student engaged in a problem solving task. Because much of the earlier and ongoing research in cognition has successfully explored the finer-grained aspects of teaching and learning, this body of research has contributed to some of the more sophisticated developmental work with instructional applications of computers. The strength of this line of research is that it can tell us how something works (e.g., a piece of software) and why it works that way -- valuable information to guide future efforts.

Another line of research is the more traditional experimental studies where one group of students uses the computer in a particular way, and a control group studies the same topic without benefit of the computer. This type of study can tell us whether or not a treatment worked in a particular setting, and when findings are combined across studies, whether that type of treatment is likely to be effective overall. However, these studies are not able to convey useful information as to how or why the treatment worked. Moreover, there are a number of controls needed to ensure confidence that the results are indeed a result of the treatment rather than a result of unintended variables.

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* The review of research that follows is intended to be illustrative rather than comprehensive. The specific studies described were selected to give the reader a sense of the type of research being conducted and the trends that are emerging from the results of that research.

The methods used for identifying sources consisted of: 1) ERIC and library searches, 2) references cited in research articles, 3) telephone calls to funding agencies (Department of Education, the National Science Foundation and the Office of Naval Research), and 4) telephone calls to researchers regarding the status of their work and to identify others working in the field. The latter two methods were found to be the most efficient in that funders and researchers tend to be quite familiar with the work of their colleagues.

The primary focus of this review is computer-tool applications as used in basic subject areas. The areas not addressed include: computer use at the college and university level; computer use in military training; instructional design issues; social, affective and equity issues; videodiscs; modeling; computer applications in art, music and vocational education.

Survey research has provided us with descriptions of trends in computer use. How many computers are in schools? How are they being used? Are there more computers in classrooms or laboratories? Do poor or minority students have as much access to computers as do well-to-do or white students?

And finally, we are just beginning to see studies of what happens when classrooms are immersed in computers -- a computer for every student, both at home and at school. For the most part, there are not yet results from these studies, but when there are, they are likely to provide a picture of classroom computer use that more closely approximates what we can and should anticipate in the near future.

There are also not yet multiple studies of a particular piece of software or type of technology (with the exception of computer-assisted instruction). And because there are so many types of computer uses in education, the limited research and evaluation dollars are thinly distributed. As a result, the evidence accumulated to date is suggestive rather than definitive.

Two interesting findings emerged as a result of this review of research. First, the amount of research focused on the use of computers for teaching and learning has grown tremendously. Vast numbers of researchers who have devoted years of their professional lives to a particular field of study, such as reading comprehension or number concepts, are now exploring how technology can contribute to learning in their field. Several new journals and many new conferences have sprung up to serve as the outlet for this work.

The second finding is the disparity between the amount of research being conducted in the use of computers with handicapped students as compared with that being conducted with bilingual students. The amount in special education is considerable and quite good; the amount of research in bilingual education is almost non-existent. While there is work-in-progress with bilingual students, it is far less common than is work in other areas such as science or mathematics, and very few of the computer applications with bilingual students are being studied in a systematic way.

REVIEW OF RESEARCH

In the following section, summaries of research on several types of computer applications are provided, along with brief descriptions of the aspects of thinking and learning believed to be tapped or facilitated by that particular use.

The Computer As a Tool for Intellectual Work

For over 20 years, workers in business and industry and scientists have used the computer as a tool to get work done more efficiently. Only very recently have educators used the computer as a tool in the classroom. The following sections contain descriptions of a wide variety of very promising tool applications.

Microcomputer-Based Labs: A Tool for the Science Laboratory

One of the more promising uses of computers is as a tool in the science laboratory. Scientists have been using computers to measure and graph phenomena for years, but they are just now making their way into classrooms. These laboratory tools, called microcomputer-based labs (MBLs), consist of probes attached to a computer. The probes, interacting with specially designed software, "sense" and measure various phenomena, such as light, heat, temperature, brain waves, pulse rate, and distance.

For example, students working with a sound probe can measure loudness or pitch, and the computer will record, display, analyze and play back the sounds being measured. Students can try to produce a "smooth" graph by humming a pure note into the microphone -- or can compare the graphs of high and low notes. They can measure the wave length of sounds that are an octave apart or compose a tune by plotting a graph of pitches they select. Activities such as these help students to get a good sense of what is meant by the pitch of a tone because they more closely associate the abstract representation of a sound with the concreteness of the sound itself.

Measuring phenomena is not new in science labs. What is new is for students to have access to a tool that takes the drudgery out of measurement and provides them with instant and accurate feedback. Without these tools, students spend most of their time in the lab measuring, recording and graphing the phenomena of interest. They tend to get lost in the detail and lose sight of the lab's focus -- the concepts it is designed to convey. With the computer taking over much of the time-consuming drudgery, students are freed up to ask the "What if?" questions that characterize the practicing scientist's world.

Below is a list of some of the benefits that MBLs have to offer students learning in the science laboratory:

1. Measurement is easier.
2. Measures are more accurate (tenth-of-second timing).
3. The links between cause and effect -- between phenomena and data are more obvious.
4. Reflection is encouraged because the computer leaves a record of the measurements made, allowing students the opportunity to look back and think through why particular results did or did not occur.

A number of studies of MBLs in science laboratories have been conducted.

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6. Marianne Wiser, Designing a Microcomputer-based Laboratory to Induce the Differentiation between Heat and Temperature in Ninth Graders, Technical Report No. 85-15, (Cambridge, MA: Educational Technlogy Center, Harvard University, 1985).

7. Marcia C. Linn, et al., "Cognitive Consequences of Microcomputer-based Laboratories: Graphing Skills Development," J. of Contemporary Educational Psychology, 1986.

Although not all results are significant or positive, overall, the studies indicate that students using MBLs grasp complex scientific concepts at a deeper level of understanding than when MBLs are not used. In addition, MBLs have been fairly successful in helping students to understand graphs -- an important skill in learning science, but one that students often fail to master. (More detail on the use of the computer to teach graphing skills is in the next section).

A critical factor in MBL use in the classroom is the way it is used by the teacher. In learning science, educators and scientists generally agree that it is important for students to engage in a process of scientific inquiry. Inquiry learning is often characterized by extensive discussions where students attempt to construct defensible explanations for observable phenomena. Researchers note that many teachers tend to use MBLs in a very structured way, with little or no discussions of experiments. In some instances, little time was devoted to independent exploration or experimentation. In fact, even projects that trained teachers in the use of inquiry-based instructional strategies for use with a particular computer application reported that teachers still reverted to a more proceduralistic approach.

Barclay, a researcher at the Technical Education Research Centers (TERC), a laboratory that has taken the lead in developing MBLs for classroom use, characterizes TERC's view of how MBLs should be used: "MBLs are tools that have the potential to empower students to be scientists and creative explorers of the world. Being a scientist means investigating the natural world, asking your own questions, finding out 'what-happens-if.' Promoting inquiry in the classroom is a creative act, a process more easily described when it goes awry than when it's nurtured."[8]

Barclay provides illuminating examples of procedural and inquiry classroom environments:

"In one MBL classroom at a large, suburban, junior high school . . . the teacher spent all the introductory time emphasizing a proper sequence of menu choices needed to follow the activity sheet instructions. When the students broke up into small groups, each with their own microcomputer and probes, the task had become 'do it right'. But what was that? They did not remember for sure what was right, and they did not read the instructions on the activity sheets either . . . They called on the teacher: 'What do I do next?' 'Is this right?' 'Why didn't it work?' Lacking any sense of the nature of the activity, the means had become a meaningless end. Completion was all; understanding was beside the point."

"A seventh grade class that used the MBL Sound Unit for several months is an example of tool-empowered inquiry. The two science teachers started by using the unit with their whole class as a group investigation. A single microcomputer was set up at the front of the class. Initially, the teacher posed the problems with the students suggesting how to find an answer and then using the probes to try it."

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8. Tim Barclay, "Coping with Inquiry," Hands On!, vol. 10, No. 1. (Cambridge, MA: Technical Education Research Centers, 1987).

"As the unit progressed, students began to pose questions. The probe and the micro became tools for studying sound -- sometimes to quickly show something, other times for an investigation that took up a whole class period. At the end of the sound unit, students did their own projects. These involved research and experiments and reports on topics that ranged from comparing the wave pictures from different musical instruments to analyzing bird songs. The teachers had made MBL their own, used it in their classrooms, and then passed it as a gift to their students to make into their own tool as well."

Mokros and Levine studied one teachers' approach to using MBLs with various groups of students. The groups were: one honors class, two average-ability classes and one class of learning disabled students with average or above average intelligence. The teacher was most structured with the special needs students, discouraging them from exploring the equipment or from trying variations of an activity presented on the lab sheets. With the honors students, the teacher allowed substantially more autonomy. All students, except those in the special needs class, showed significant gains in their overall scores in math skills and in understanding scientific concepts. The researchers plan to conduct further studies where learning disabled students use MBLs in an inquiry-based instructional setting.[9]

The results of these classroom observations illustrate two points made earlier. One, contextual factors interact with specific computer uses to promote or hinder learning. Regardless of the potential a particular computer application might have, if teachers use it to promote procedural or factual learning, to the exclusion of exploration for qualitative understanding, then the full potential of the computer will never be realized.

Second, teaching for inquiry, for deeper levels of understanding, has always been difficult for teachers. The research in cognitive science has revealed that there are many subtle, tacit dimensions to thinking and problem solving. These research findings have not found their way into the training of teachers. They are not generally part of the teacher education curriculum, and there is very little research focused on understanding how teachers conceptualize the teaching of thinking or how to change their conceptions when appropriate.

Enthusiasm surrounding MBLs is quite high. While many science teachers have yet to discover them, steady progress is evident: teachers are being trained, new software and other instructional units are being developed, and studies are being conducted.

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9. Janice R. Mokros and Deborah L. Levine, "The Use and Impact of MBL as a Function of Learner Characteristics," Unpublished Paper, (Cambridge, MA: Technical Education Research Centers, ND).

Graphing Programs

National test results show that students do poorly at graphing, despite the fact that graphing receives considerable attention in both algebra and geometry classes. And yet graphs are a powerful way to see functional relationships, for example, relationships between temperature change and time, or pulse rate and exercise. Students who have a solid grasp of graphing skills are more adept at studying changes in physical and social phenomena and at understanding the effects of various interventions. Thus, mastery of graphing skills is important to students' progress in both the physical and social sciences.

Both MBLs and game-like activities have been designed to teach graphing skills. The computer is an ideal tool for teaching graphing skills: it provides an instant representation of the relationships between variables and allows students to see graphs in real-time as an experiment unfolds. Results of studies where students use the computer to develop graphing skills are more consistently positive than with any other area of computer use. Studies using each approach are described below.

Thornton used MBLs with sixth-grade students who worked in groups of three to produce and observe graphs of motion in real time. The children's task was to produce a particular graph by moving about the room. This was possible because of sonar detectors and software that "sensed" the direction and speed of students' movements (See Figure 1). For example, one student would play the role of the "dancer," moving about the room under the direction of two peers who offered advice about which way to move. Mokros reported that when a graph was completed, students critiqued their own performance, and often, the dancer would beg for a chance to repeat the graph until he or she was satisfied with the results.[10]

The findings showed that students exhibited a solid understanding of distance and velocity graphs and achieved a mean score of 85 percent correct on a test of related graphing skills. Several other studies using MBLs to develop graphing skills show similar results.[11, 12]

Game-like strategies are a second approach to teaching graphing skills. Dugdale and Kibbey developed Green Globs and Algebra Arcade to help

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10. Ron K. Thornton, "Tools for Scientific Thinking: Microcomputer-based Laboratories for the Naive Science Learner," Technical Report 85-6, (Cambridge, MA: Technical Education Research Centers, 1985).

11. Marcia C. Linn, et al., "Cognitive Consequences of Microcomputer-based Laboratories: Graphing Skills Development," Journal of Contemporary Educational Psychology, 1986.

12. Janice R. Mokros and Robert F. Tinker, "The Impact of Microcomputer-based labs on Children's Ability to Interpret Graphs," Journal of Research in Science Teaching vol. 24, No. 4, 1987, pp. 369-383.

students understand the relationships between algebraic equations and their corresponding graphs.[13] According to Rowe, one skill that seems to distinguish bright students with an aptitude for mathematics from other bright students who are less able in mathematics is their ability to look at polynomial equations and to quickly visualize what their graphs would look like.

These computerized graphing games develop this ability by asking students to write an appropriate equation for a given graph. In Green Globs, the computer displays coordinate axes with 13 green globs scattered randomly on the screen. The student's task is to hit all of the globs with graphs which are specified by typing in equations. When a glob is hit, it explodes and disappears. The student's equation is instantly displayed in graphic form, so the student receives immediate feedback on his or her ideas (See Figure 2).

Dugdale and Kibbey conducted a formative evaluation of Green Globs. The results showed that treatment students increased their graphing abilties from pre- to posttest and that their gains were greater than those of control students who were unintentionally exposed to the graphing games, but for a short amount of time.

Rowe studied the use of Algebra Arcade -- an outgrowth of the Green Globs graphing program -- with bright, female high school students who exhibited math anxiety. The results showed that students who used the computer were much more likely to explore relationships, try out ideas, try more experiments, and ask more questions, such as "What if we made the numbers on the coordinates small by making the scale spaces large, would it speed up our calculations? What would we miss?" These results carried over to science laboratory investigations. The computer students were more likely to explore the differences in the interplay between phenomena and their representations in models, data tables and graphs.[14]

The graphing applications described above are model instances of appropriate use of computers for learning. In both approaches, the desired instructional results were more readily achieved because of the unique features that could only be provided by a computer. The instant representation and feedback afforded by the computer frees students from the cognitive drain of lower-level tasks (e.g., plotting points on a graph by hand) and allows them to focus on the the more abstract, complex and intellectually meaningful concepts.

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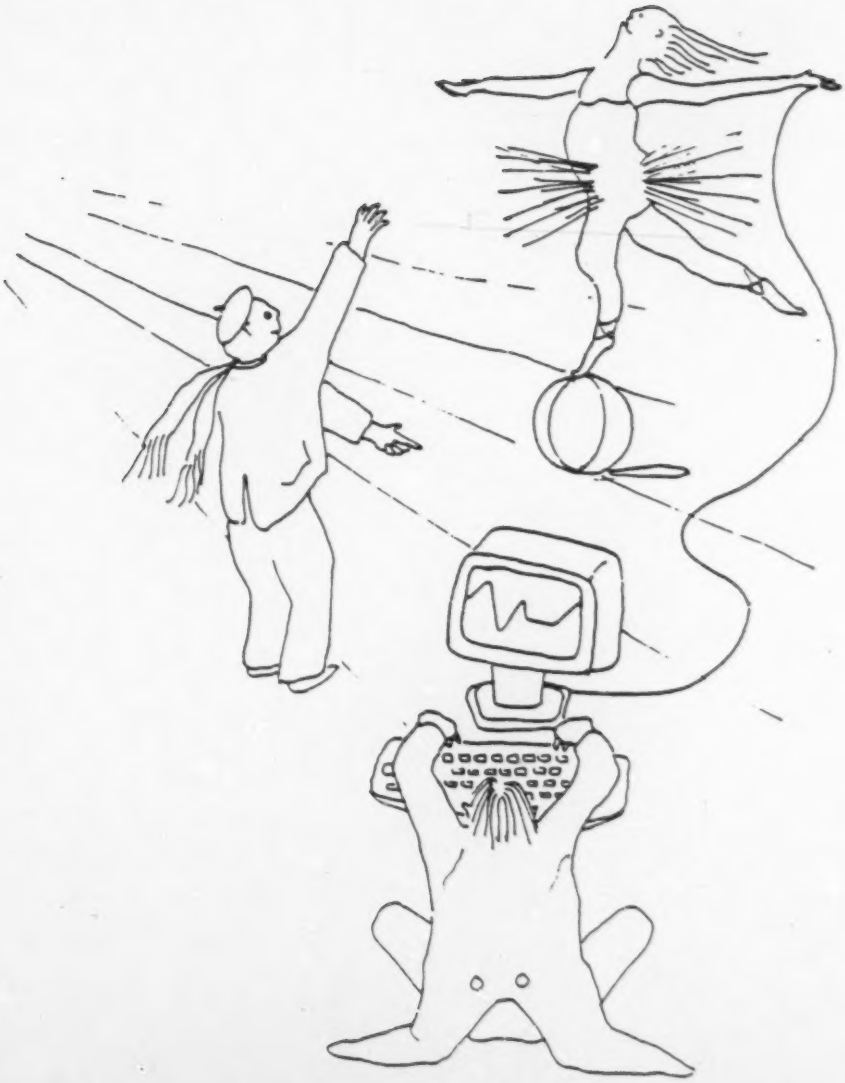
13. Sharon Dugdale and D. Kibbey, "Prototype Microcomputer Courseware for Teaching High School Algebra," SED80-12449, (Univ. of Illinois, Urbana, Final Report to NSF, 1980).

14. Mary Budd Rowe, "Computer Graphics in the Science Laboratory: An Experiment," unpublished paper, Gainesville, FL: University of Florida, 1986.



Artwork by Rob Peters

Figure 1: Students Using MBL to Study Motion

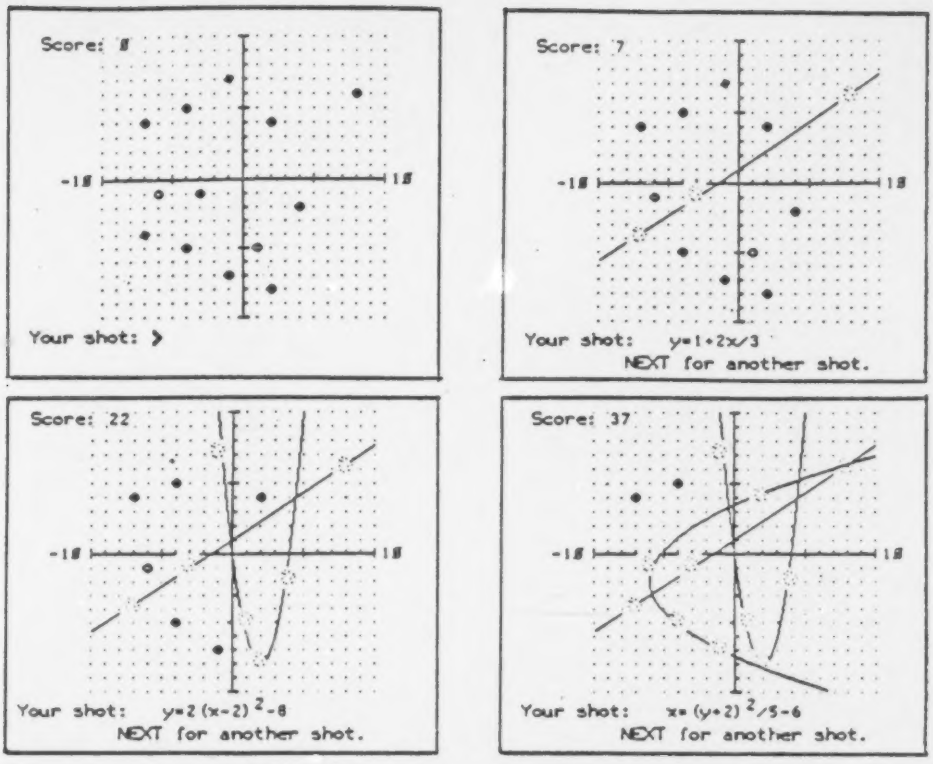


Fig. 2 Sequential displays from a game of Green Globs. The student types in equations, which are graphed by the computer. The green globs explode as they are hit by the graphs. Shown is the initial display of 13 globs, followed by the student's first three shots.

Simulations

Computer programs designed to simulate complex processes that occur in the world are available in several disciplines, including the physical and social sciences. The computer simulates these processes through a variety of activities, including writing messages, "acting-out" the process of a phenomena through illustrations and animation, and drawing graphs based on simulated data. Examples of simulations range from programs that allow students to see how an object behaves in a Newtonian, frictionless environment, to programs that allow students to play the roles of world leaders making important, high-impact decisions.

Some simulations are able to represent complex scientific concepts in ways that are impossible without computers. In some cases these representations increase the accessibility that students have to concepts that have been traditionally quite difficult to grasp.

Physical Science Simulations

For example, in physics, several pieces of software have been developed to simulate an artificial, frictionless world where the laws of Newtonian physics can be examined. Students can perform experiments and observe results that could never be seen in a friction-filled, classroom environment. The results of studies using such software are mixed. Hewson used two computer simulations to diagnose and correct first-year college physics students' misconceptions about speed and force. In the speed study, racing cars moved across the screen representing relative motion; in the force study, rockets represented the principles of force as related to energy and momentum. Hewson reported that students clearly understood speed better after using the race car program but did not improve in their understanding of force after working with the rocket programs.[15]

White also developed a computer simulation to teach high school students to solve force and motion problems using Newton's laws of motion. Her studies showed that students who used the program for only one hour improved significantly more than students who did not use the program.[16]

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15. Peter W. Hewson, "Microcomputers, Conceptual Change and the Design of Science Instruction: Examples from Kinematics and Dynamics," South African Journal of Science, vol. 80, 1984.

16. Barbara White, "Designing Computer Games to Help Physics Students Understand Newton's Laws of Motion," Cognition and Instruction, vol. 1, No. 1, 1984, pp. 69-108.

Social Science Simulations

Non-computer based simulations have long been used as strategies for increasing students' interest in and understanding of social studies. Although, research indicates that simulations do not necessarily improve the learning of content or skills any more than does conventional instruction, they do seem to increase students' motivation, attitudes, and active participation. [17] Schug and Kepner report that simulations are more effective ways of involving students in decision-making processes and help to convey complex representations of reality better than print materials or classroom lecture and discussion. [18]

Only recently have social science simulations been put on the computer and very little research has been conducted to date. However, Glenn believes that the use of the computer can streamline the learning that results from simulations, because the computer relieves the teacher and students from many of the time-consuming and routine managerial tasks necessary to maintain a simulation. For example, the computer can take care of record-keeping responsibilities, report on the status of quantitative factors and decisions, manipulate computations, and make projections. When students and the teacher are freed from these mundane and time-consuming managerial tasks, they can devote more attention to the concepts, relationships, trends and patterns inherent in the topic under study.

Graduate students and faculty at the University of Michigan have developed two computer-mediated social science simulations where students play the role of national or world leaders engaged in the dynamics of governmental or international affairs. One simulation represents the Arab-Israeli conflict and the other the United States Constitutional Convention. Working in teams of five or more, each student assumes the role of a particular individual or group represented in the conflict, such as the president or king of the country, the defense minister, leader of a guerilla group, or diplomatic envoy. *

Each simulation takes three months to complete, including time to research, plan, execute and debrief. Students begin with a scenario that projects them slightly into the future and is played out through various forms of communication. These communications include private messages between world leaders,

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17. Allen Glenn and Lee Ehman, "Computer-based Education in Social Studies," (Bloomington, IN: Indiana University, Social Studies Development Center and ERIC Clearinghouse for Social Studies/Social Science Education, 1987).

18. Mark C. Schug and Henry S. Kepner, Jr. "Choosing Computer Simulations in Social Studies," The Social Studies, vol. 75, September/October 1984, pp. 211-215

* This simulation , called the International Communications Simulation (ICS), was originally developed for use by undergraduates in a course on Arab-Israeli conflict at the University of Michigan, and has been modifed for middle and high school students. Contact Tom Switzer, Dean, School of Education, University of Michigan, Ann Arbor, MI, 48109.

press releases announcing policy decisions and responses, and action forms such as changes in trade policies or declarations of war. After the preparation and simulation, students engage in a two-week debriefing session, where they reflect on their various moves and strategies in light of feedback from the University-based simulation management team and information they have gleaned through their research.

Participating classes are provided with the simulations and supporting background material to use in researching the groups involved in the conflict. Their goal is to understand both the issues and the individuals they are to portray in the conflict.

Each team has access to a microcomputer and a modem that connects them to the host computer at the University of Michigan. The staff at the University manages the simulations and provides feedback to teams, reviewing all forms of communications and judging the propriety of the communications or actions to ensure integrity of the simulation.

Teams also interact with each other through this communications network. These teams are dispersed over 15 states and countries including Mexico, West Germany and France. This year, schools in three more countries will join the network.

Nearly 120 schools have participated in the International Communications Simulation and informal evaluations have shown a number of positive effects. Students are more motivated to engage in high-level critical thinking, have a better understanding of the dynamics of political affairs, appreciate the variety of perspectives on issues, gain experience with the computer and computer-mediated communications, develop insight into the research process, acquire research skills, have an opportunity to practice writing clear, forceful prose; and experience the challenge of making important decisions and the seeing the consequences of their decisions.

The live, interactive communication with specialists at the University and students in other countries provides a hint of reality and immediacy to the simulation as well as relieving the teacher of some of the intellectual responsibilities involved in analyzing students' work.

Students Design Their Own Simulation. Rather than engage his students in using an already prepared simulation,involved five classes of middle school students in developing a simulation for the Great Depression. The rationale for having students engage in the design and development is that they are more likely to learn complex concepts at a deeper level of understanding because they are forced to make explicit the models and processes underlying the simulation. Students must work through decision patterns and specify the consequences of each decision. [19]

Although no formal evaluation was conducted, Roessler reported that in planning the simulation, his students learned factual information about the Depression, got a sense of how the various facts fit together and developed a better

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19. Michael Roessler, "Students Design a Depression Simulation," Social Education vol. 51, No. 1, 1987.

understanding of what it was like to have lived through the Depression. He also indicated that his students learned to appreciate the benefits of careful research, developed a better understanding of the components of good writing, and gained insights into modeling and the structure of simulations.

Roessler's students reported that the activity was interesting and enjoyable despite the hard work and indicated that ". . . it was just the thinking you had to do in order to write and type the program," and ". . . you gave the responsibility to us and we had to handle that, which was its own learning experience." (p. 51). Roessler's class decided to market their simulation: at the latest report, they had received 130 orders.

In summary, there are a broad range of types of simulations, but very few have been studied in a research setting. Because of the wide variability in the types of simulations, it would be difficult to generalize about the effects on learning of simulations in general.

Multi-Media Programs

Several pieces of software have been developed in conjunction with videodisc and other forms of media to provide context-rich learning environments. Probably the most popular of these is the Voyage of the Mimi program which takes advantage of several forms of media, including the classic television series by the same name, to provide a two-year mathematics and science curriculum.

The series, aimed at students in grades four through six, includes four learning modules, each featuring a different type of software and assorted print materials. The software models a variety of adult uses of technology, including a training simulation, a microworld, a programming environment, and a microcomputer-based physics lab. All of the video programs are closed-captioned in two languages: English and Spanish, and since one of the main characters is deaf, signing is used throughout. A key element of the design of the Voyage of the Mimi has been the involvement of teachers thoughout all phases of development. [20]

The television series depicts teen-agers accompanying two young scientists on a whale research expedition. Each television program consists of two parts: a 15-minute dramatic episode that chronicles the continuing adventures of two scientists and their young assistants on a 6-week research voyage to locate and study humpback whales in the Gulf of Maine; and a 15-minute documentary

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20. The Voyage of the Mimi was developed by the Department of Education through researchers at the Bank Street College, Center for Children and Technology. Cynthia Char and Jan Hawkins, "Charting the Course: Involving Teachers in the Formative Research and Design of 'The Voyage of the Mimi'," in Roy Pea and Karen Sheingold (eds.), Children and Microcomputers: Theory, Research, and Development from Bank Street College's Center for Children and Technology (Working Title), (Norwood, NJ: Ablex Publishing, in press).

'expedition' that builds upon the science and math themes presented in the dramatic installment. Because the video documentary segments show the scientists in their actual working environment, students get a sense of the scientific processes and procedures as they are used in actual work situations. Students can see how math and science skills are used in the real-world.

The four learning modules that accompany the series each have a different set of software and print materials including: simulation games of navigation problems, a MBL package for gathering and graphing temperature, sound, and light data, and a computer simulation that allows students to explore the food chain, species populations and the impact of human intervention on ecosystems. All of the software is accompanied by teacher guides that include a comprehensive treatise on whales and suggestions for classroom activities.

Most of the software and films are available on videodisc. For example, a student can stop the motion of the film of a whale surfacing, analyze the image of the whale frame by frame, and look at the process backwards or in slow motion. The videodisc reader can quickly shift from one area of the disk to another so that a student could flip back and forth between two similar scenes. Graphics can be superimposed over the picture so that, for example, a student could "measure" the size of a whale's tail using a graphic ruler drawn on the screen over the film of a whale.

The learning modules were field tested over a two-year period with 82 teachers and staff developers from 13 districts across the country to obtain their reactions to the videotape and software. The researchers observed the use of the materials in classrooms, conducted student and teacher interviews and collected daily logs maintained by teachers regarding their perceptions of the materials as they were being tried out.[21]

The researchers conducted one-week training sessions for teachers in the principles of inquiry-based instruction. The integration of inquiry teaching strategies with the use of technology was the primary goal of the Mimi project. Inquiry teaching should promote an environment in which ambiguity is tolerated and students' questions are encouraged. The researchers found that few teachers were able to adopt or sustain a style of teaching that encouraged inquiry. Teachers tended to ask the majority of the questions and rewarded students for guessing correctly. The types of questions typically asked ranged from discrete pieces of information (e.g., What kind of whales were the scientists studying?) to more complex concepts (e.g., What is a good strategy for finding your location at sea?). Teachers required ongoing help in maintaining a classroom climate that emphasized reasoning rather than right answers, and only teachers who had experience in inquiry-based instruction used the materials in an open-ended way. The authors of the

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21. Margaret A. Honey, et al., "Teaching Technology: Creating Environmments for Change," Paper presented at the American Educational Research Association, Washington, DC, 1987.

Mimi evaluation report provide an example of an inquiry-based questioning strategy that they consider more likely to promote the development of students' reasoning and problem-solving abilities.

"A teacher showed an episode in which the crew of the Mimi confronted a number of problems, from equipment failure to getting lost. He asked the children what solution strategies they noticed the characters using. At the same time, the teacher encouraged the children to generate alternative solutions to the problems and to recount related incidents from their own lives. The teacher created a matrix on the board into which he entered students' responses to the patterns of strategies that emerged" (p. 6).

By having the students recount related incidents from their own lives, the teacher helped them to tie their own experiences to those of the scientsts', thereby providing the students with more opportunities to make the experience meaningful and more thoroughly understood. Instead, the researchers found that teachers tended to maintain their traditional role of information dispenser by reorienting activities and discussions toward convergent goals, such as factual recall of details.

They found that it was important to provide training in the scientific concepts covered in the materials and to give teachers rich and varied suggestions for classroom activities. Of the teachers using the Mimi materials, 100% reported that they intend to use them again and recommended the materials to other teachers.

Data Management Tools

Students in some classrooms are also using data management tools to store, update, retrieve, organize, sort, format, and perform computations on data on any subject . Such systems are used frequently in business and have many applications in the classroom. Unfortunately, while there are numerous anecdotal reports enthusiastically describing their use in classrooms across the country, there is very little research documenting the effects of such tools in learning.

Hunter lists typical questions that can be addressed with a data base on world cultures (See Figure 3):[22]

- What countries had an average annual growth rate of less than 1 percent during 1960-1981? In what areas of the world are these countries located?
- In what areas of the world would you expect to find countries with an annual population growth rate greater than 3 percent?
- What countries' annual growth rate will result in population more than doubling between 1980 and 2000? (p. 39).

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22. Beverly Hunter, "Knowledge-Creative Learning with Data Bases," Social Education, vol. 51, No. 1, 1987.

Figure 3, Sample Record from World Cultures File

WORLD CULTURES

COUNTRY: Mexico
AREA OF THE WORLD: North and Central America
CONTINENT: North America
TYPE OF GOVERNMENT: Federal Republic
MAJOR POLITICAL PARTIES: 1
CAN THE PEOPLE VOTE?: Yes
Restrictions: 18 or older
LEADER: Miguel de la Madrid Hurtado
Title: President
Comments:

POPULATION

POPULATION (Millions): 0,075.70
Year: 1983
Projected—Year 2000: 0,115.00
% Ann. Growth Rate 1960–81: 3.2
Population per Square Mile: 00,098.0
Percent Urban: 66.7
Median Age: 17.1

ETHNIC GROUPS: Mestizo, Indian, European

RELIGIONS: Roman Catholicism, Protestantism, Judaism
LANGUAGES: Spanish, Indian Languages

NEWS SOURCE:
ENTERED BY: DATE

SOURCES OF INFORMATION

1. Kaleidoscope-Current World Data.
ABC-Clio, Inc. Santa Barbara, CA.
Country; Mexico Year 1984

2. Development Data Book (ed. Harriet Baldwin).
The World Bank.
Washington, DC, 1984.

Life expectancy, infant mortality, literacy, calorie needs and school enrollment data are from World Bank. All others from Kaleidoscope.

EMBASSY

Name: Embassy of Mexico
Street: 2829 16th St. NW
City: Washington, DC Zip: 20009

COMMUNICATION

RADIOS PER 1,000 POP.: 0,288
TV SETS PER 1,000 POP.: 108
TELEPHONES PER 1,000: 071

RADIO STATIONS: 0,740
TV STATIONS: 0,120
DAILY NEWSPAPERS. 0,340
NEWSPAPER CIRCULATION: n.a.

And from a data base on inventions (See Figure 4):

- **Was there a particular point in history when many inventions were made that depended on the use of electricity? What technology developments made possible this sudden explosion of invention?**
- **It is sometimes said, "Necessity is the mother of invention." Assemble data to support or deny that statement. (p. 42).**

Figure 4: Inventions File

INVENTIONS & TECHNOLOGY

INVENTION: Power Loom
YEAR: 1787 TYPE: Textiles
DESCRIPTION: A machine used for weaving fabrics.

IMPACT: A major invention which expanded the textiles industry. Improvements have been made in the loom but the machinery used by the textile industry today remains largely the same.

INVENTOR: Edmund Cartwright
BORN: 1743 DIED: 1823 SEX: M
NATIONAL ORIGIN: England
NEED FOR INVENTION: There was a need for a labor- and time-saving device in weaving cloth.

ENABLING TECHNOLOGY:
— Earlier hand looms
— Fly Shuttle
— Spinning Jenny

Figs. 3 and 4 from B. Hunter, Vol. 51, No. 1, Social Education, Jan. 1987

Hunter lists some of the skills that students need in order to use data base systems are:

- o Define a problem in specific terms, perhaps breaking it up into several small problems.
- o Identify specific data needed to address that problem.
- o Locate and extract relevant data from the larger collection of data.
- o Put the data in a useful order (e.g., by size, date, age).
- o Organize printed lists or arrangements of the data.
- o Use the information obtained to identify patterns such as relationships or trends (as well as cases that depart from the patterns).
- o Identify further information needed in order to explain, interpret or investigate cause and effect relationships.
- o Communicate findings to others.

Because students actively work with the data and use it for their own purposes, they are likely to be more involved in the learning activity and to integrate it into their existing knowlege base so that it becomes functionally useful and meaningful. Interacting with the data helps students to synthesize, sort and see relationships in the data base and to see a variety of ways that information can be used. They begin to see that they can ask their own, important questions, rather than merely respond to questions put to them by an authority figure. Because electronic data files are easy to change and expand, students can recreate them to suit their own needs.

One of the few studies conducted on the use of data bases involved fourteen teachers and 665 students in grades 7 through 12. One group of students used a computerized data base (PFS: Curriculum Data Bases for U.S. History and for U.S. Goverment), while the control students used the same curriculum-specific data printed on 4 x 6 index cards housed in plastic file boxes.[23]

The key difference between the activities engaged in by the two groups was in the level of structure. Students in the computer group received detailed instructional activities in how to use the computerized data base system to solve problems, define information, develop data retrieval specifications, interpret and evaluate retrieved data, and revise retrieval specifications. The control students did not receive this step by step guidance. In addition,

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23. Charles White, "The Impact of Structured Activities with a Computer-Based File-Management Program on Selected Information-Processing Skills," doctoral dissertation, (Indiana University, DAI 47: 513A, 1986); and see also C. White, "Developing Information-Processing Skills Through Structured Activities with a Computerized File-Management Program," Journal of Educational Computing Research, vol. 3, No. 3, 1987.

the design of the data-base program imposed more of a structure in manipulating data than was possible with the students who used the index-card system.

Using a carefully controlled experimental design, White found that, on a test of information processing skills, those students using the computer data base program in concert with structured activities significantly outperformed the control students who carried out the same structured curricular activities. The specific abilities measured on this Information Processing Scale were: 1) to recognize sufficient information to solve a given problem, 2) to recognize whether the information they were presented was relevant to a given problem, and 3) to discriminate between efficient and inefficient organizations of information to solve a given problem.

It is possible that the significant effects on the treatment students could have been due to the detailed instructions in using a data base system for problem solving rather than to the use of a computerized system. White recognized this problem but argued that "the evident confounding of computer interaction and structured print-based activities also matched what would be expected of instruction in schools: few educators could justify pursuing the former without the latter." (p. 368). Future research should explore the option of providing non-computer students with detailed instruction in using data for problem solving, thereby controlling for the effects of the two key components of this study.

A number of other "studies" reported impressionistic findings of students' using computerized data bases in the classroom, citing a range of responses, including enthusiastic student involvement, better understanding of concepts, generalizations and relationships, and persistence and cooperation among students working within groups [24, 25, 26, 27, 28, 29].

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24. M. Rothman, "Using the Microcomputer to Study the Anatomy of Revolution," The Computing Teacher, vol. 10, September 1982.

25. Tama Traberman, "Using Interactive Computer Techniques to Develop Global Understanding," The Computing Teacher, September 1983.

26. Tama Traberman, "Using Microcomputers to Teach Global Studies," Social Education, vol. 48, February 1984.

27. Roxanne B. Medrinos and Donald M. Morrison, "The Irish Immigrant: How the Program Works," Classroom Computer Learning, vol. 7, No. 42, 1986.

28. D. M. Morrison and J. Walters, "IMMIGRANT: A Social Studies Simulation for AppleWorks," in Computers in the Classroom: Experiences Teaching with Flexible Tools, C. Thompson and L. Vaughn (eds.), (Chelmsford, MA: Northeast Regional Exchange, Inc. 1986, ED 268 013).

29. D. M. Morrison and J. Walters, "The Irish Immigrant: Origins of the Project," Classroom Computer Learning, vol. 7, October 1986.

Word Processing

According to Becker's 1985 survey of computer use, word processors account for about ten percent of the ways in which computers are typically used in schools. Although girls tend to use the computer for word processing more often than do boys, the use of the word processor is approximately the same across grade and ability levels.[30]

Word processors offer writers ease in editing, neat printed copy, and tend to make the process of writing more public. They often incorporate features that hyphenate words and check on spelling, and some of the more complex correction programs comment on the screen about style and grammar, while others catch errors and report them to the writer.

Research has revealed that students' writing does not necessarily improve merely by using the word processor. While students may be inclined to write more text,[31] and enjoy writing more when they use a computer,[32, 33, 34] Daiute found that students' corrections were often mechanical rather than substantive.[35]

A number of key differences in the writing and revision process of expert and novice writers have emerged from research on writing. Experienced writers revise extensively, while beginning writers tend to make superficial changes, such as spelling or word choices. In fact, beginning writers often don't even read over their text when asked to revise. Instead they rewrite their text from memory. Daiute suggests that young or novice writers simply don't know what to do when asked to revise. Revision is a complex cognitive process.[36] It requires that writers evaluate their writing, diagnose problems and figure out how to correct the problems.[37] Merely easing the physical requirements of writing does little to ensure that these cognitive abilities are developed.

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30. Henry J. Becker, Instructional Uses of School Computers: Reports from the 1985 National Survey, Issue No. 4, (Baltimore, MD: Center for Social Organization of Schools, The Johns Hopkins University, 1987).
31. Colette A. Daiute, "Psycholinguistic Foundations of the Writing Process," Research in the Teaching of English, 1981, pp. 5-22.
32. Colette A. Daiute, "The Effects of Automatic Prompting in Young Writers," Interim Reports to the Spencer Foundation, 1981, 1983.
33. R. M. Collier, "The Word Processor and Revision Strategies," College Composition and Communication, vol. 34, 1983, pp. 149-155.
34. L. Bridwell, et al., "Revising and Computing: Case Studies of Student Writers," in S. Freedman (ed.), The Acquisition of Written Language: Revision and Response, (Norwood, NJ: Ablex, 1985), pp. 172-194.
36. Colette A. Daiute, "Physical and Cognitive Factors in Revising: Insights from Studies with Computers," Research in the Teaching of English, vol. 20, 1986, pp. 141-159; also Writing and Computers (Reading, MA: Addison-Wesley, 1985).
37. L. Flower, et al., "Detection, Diagnosis, and the Strategies of Revision," College Composition and Communication, vol. 37, 1986, pp. 16-55.

Researchers have begun to identify key strategies that seem to be essential for reading, critiquing and improving one's own written work. Some of these strategies are being incorporated into software programs for writing. For example, Daiute and her colleagues have developed a computer-based program to help students be more objective about their writing. The program, called Catch, encourages students to take the point of view of the reader as they revise and prompts students to focus on the meaning of a passage rather than on its more superficial aspects. For example, one option in the software prompts the writer with, "The highlighted words may be too vague. If so, give more specific information." The student has control over whether or not to use any of the 22 prompts.[38,39]

Studies with middle school students showed that students using the Catch software made more interactive revisions when compared with students who used only a word processor. Interactive revisions are more substantive and students work with the orginal draft rather than redraft their text from memory. It also means that they make more changes within the body of the text rather than adding changes to the end. These results are particularly signficant because interactive revising is quite rare among beginning writers of all ages.

The authors offer several reasons for the increased and closer revision of drafts. Besides modeling a self-prompting strategy, the fact that suggestions were repeatedly offered by the computer may have helped students to solidify the in-class instruction they were receiving on revision strategies. It also may have helped focus students' attention on the text, encouraging them to engage in more careful reading.

Findings of learning disabled (LD) students using the word processor are consistent with those from studies of regular students. In a year-long study, learning disabled students who used the word processor, in conjunction with receiving instruction in a process approach to writing, made significant gains in their writing ability as compared with a control group that did not receive the special intervention.[40]

Graham and MacArthur also studied LD students who were taught revision strategies as they used the word processor. This instruction resulted in increases in both the number of revisions and the proportion of revisions that affected meaning. In addition, the students wrote longer and higher quality essays[41]

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38. Colette A. Daiute, "Rewriting, Revising and Recopying," Paper presented at the meeting of the American Educational Research Association, New Orleans, April 1984.

39. Colette A. Daiute and John Kruidenier, "A Self-questioning Strategy to Increase Young Writers' Revising Processes," Applied Psycholinguistics, vol. 6, 1985, pp. 307-318.

40. L. B. Kerchner and B. J. Kistinger, "Language Processing/Word Processing: Written Expression, Computers and Learning Disabled Students," Learning Disability Quarterly, vol. 7, 1984, pp. 329-335.

41. S. Graham and Charles MacArthur, "Improving Learning Disabled Students' Skills at Revising Essays Produced on a Word Processor: Self-instructional Strategy Training," unpublished raw data, 1987.

Many students find it very difficult to come up with ideas for what to write about and often "freeze-up" before they even get started. Morocco and Neuman studied regular and mildly learning disabled students using the word processor and found that students were more successful in generating ideas for writing and producing a first draft when their teachers taught them strategies for generating ideas during writing. The students could then generalize these procedures to other writing situations.[42] In another study, Morocco & Neuman reported that special education students' motivation and sense of ownership of their writing were enhanced when teachers provided help in strategies for approaching writing tasks, rather than giving substantive help with content or focusing prematurely on mechanics.[43] While their research does not compare the relative effectiveness of using computers, it does guide teachers of writing in how to assist students.

Ellis and Sanbornie found that the writing of students who were asked to take a position and defend it improved when they were given a specific seven-point strategy for defending a position in writing. They improved both with and without the use of a word processor, but students who used a word processor coupled with an idea processor (outlining program) showed the most improvement.[44]

Several studies have also shown the importance of students learning keyboarding and word processing skills.[45, 46] MacArthur et al. found that typing efficiency was highly correlated with length, quality and story structure and recommend daily keyboarding instruction if a word processor is to be used to teach writing.

In summary, it appears that the word processor alone does not significantly enhance the writing abilities of either regular or learning disabled students, but when coupled with instruction in strategies for writing (e.g., strategies for generating ideas or for revising) tend to produce more fluency in writing and revisions that affect meaning.

There are two additional aspects to writing on a computer that seem to enhance student motivation and interest in writing. One is the printed output that gives students the power to produce neat copy with ease, and the other is the appeal of communication with one's peers, both at home and in distant lands.

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42. Catherine C. Morocco and S. B. Neuman, "Teachers, Children and the Magical Writing Machine," Final Report, (Newton, MA: E. D. C., 1987).

43. C. Morocco and S. B. Neuman, "Word Processors and the Acquisition of Writing Strategies" Journal of Learning Disabilities, vol. 19, 1986, pp. 243-247.

44. E. Ellis and E. Sabornie, "Effective Instruction with Microcomputers: Promises, Practices and Preliminary Findings," Focus on Exceptional Children, vol. 19, No. 4, 1986, pp. 1-16.

45. Charles A. MacArthur, et al., Learning Disabled Students' Composing with Three Methods: Handwriting, Dictation and Word Processing. Research report #109 (College Park: Univ. of Maryland, Institute for the Study of Exceptional Children and Youth, 1986).

46. S. B. Neuman and C. Morocco, Two Hands is Hard for Me: Keyboarding and Learning Disabled Children. (Newton, MA: Univ. of Lowell, Education Development Center, 1986).

A number of studies describe students enthusiastically producing letters, books, newspapers and other publications on the computer . For example, students using a multi-component package called QUILL, designed a brochure describing their city that included sections on the city's schools, clothes, trapping and hunting, etc. These brochures were then used by the city council to answer tourism requests for information. The ability to produce professional looking publications will be even more enhanced with the recent introduction of desk-top publishing programs.[47]

Telecommunication networks, both within a classroom and across long distances, appear to be highly motivating devices for encouraging students to communicate through writing. The next section contains descriptions of a wide range of electronic telecommunication networks.

Electronic Networks

Electronic networks allow individuals or groups to communicate with one another using computers that are connected through local area networks (LAN) or through telephone lines. These communication devices are used widely in the professional world, ranging from the fast paced stock market trading to the more thoughtful explorations of scientists working to solve the mysteries of the physical world. Now students and teachers are communicating with one another across the classroom and across the world. Electronic networks are being used in every subject area and at all but the earliest grade levels.

Riel describes the Computer Chronicles Newswire project, where third and fourth grade students in Alaska communicated with students in California about events and issues in their school and community. Each site published a newspaper that consisted of articles selected by the student editorial board. Through this process, students engaged in dialogues with others from a different culture, struggled with communicating clearly in writing, and gained valuable experience in evaluating and revising compositions.[48]

Bilingual Communication Across Countries

Through the use of a computer network called De Orilla a Orilla (From Shore to Shore), limited and non-English speaking students in New England and California are paired with Spanish-speaking students in Mexico and

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47. Andee Rubin and Bertram Bruce, "Learning with Quill: Lessons for Students, Teachers and Software Designers," in Taffey Raphael (ed.), Contexts of School-based Literacy, (New York: Random House, 1986).

48. M. M. Riel, "The Computer Chronicles Newswire: A Functional Learning Environment for Acquiring Literacy Skills," Journal of Educational Computing Research, vol. 1, 1985, pp. 317-337.

Puerto Rico for the purpose of improving their writing skills. According to Sayers and Brown, initiator of the project, "Students in bilingual education programs need authentic contexts for mother-tongue writing if they are to develop and maintain basic literacy skills and then transfer them to English academic settings. Second language students need authentic contacts with native speakers and plenty of practice in a range of language skills, including reading and writing, if they are to develop cultural awareness and communicative competence." (p. 1). Sayers considers computer networks to be a "perfect fit" with the special needs of bilingual students.[49]

Orillas students are writing newspapers, playing the roles of writers, reporters, editors and correspondents. In this case, their classroom computer has become an international teletype. Another aspect of the project involves students in using an integrated database system to organize collections of proverbs in a multi-national investigation. Proverbs elicited from students' families were sorted and compared by theme and context, and resulted in a book of proverbs jointly produced by all the sister classes in Project Orillas.

Future plans include involving both new countries (Argentina, Canada and Cape Verde) and additional language groups (American Sign Language, Cape Verdean Creole, French, Jamaican Creole and Puerto Rican Sign Language).[50]

International Communications Network

Another international computer communications network involves students in eight secondary and college groups in the United States, Japan, and Israel. The project is designed to permit students from different cultures to use one another as resources for learning about their social, cultural and physical worlds. Participating students explore topics such as peaceful alternatives to war, how schools prepare students for careers, peer violence, and water supply systems.

For example, U.S. students received a message from a Japanese student describing a situation in which teenagers mentally, and sometimes physically, exclude or bully a student until the student is driven to suicide. The U.S. students asked questions to try to understand the problem and suggested ways of handling it. The Japanese students developed and conducted a small survey to understand more fully the extent of the problem. According to Riel, this intercultural communication led to insightful discussions about other aspects of culture, including the meaning of friendship and peer relations.[51]

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49. Dennis Sayers and K. Brown, "Bilingual Education, Second Language Learning and Telecommunication: A Perfect Fit," CALL Digest, vol. 3, No 5, Eugene, OR: ICCE, 1987.

50. Dennis Sayers, "Bilingual Sister Classes in Computer Writing Networks," to appear in Donna Johnson and Duane Roen, (eds.), Richness in Writing, (Longman, 1987).

51. M. M. Riel, "Intercultural Learning Network," CALL Digest, vol. 3, No. 5, Eugene, OR: ICCE, 1987.

Communicating Science Across the Nation

Children in fourth through sixth grades are now collecting, recording and comparing the range of acidity or alkalinity of common liquids, including rain, using an electronic network established through a joint venture among the Technical Education Research Centers (TERC), the National Geographic Society and the National Science Foundation. [52]

This National Geographic Kid's Network allows students to share information they collect, with each other and a specially designated scientist, on topics such as weather forecasting, water pollution and food growing. All this happens through a nationally-linked telecommunications network. The topic scientist uses a powerful central computer to summarize the data the kids feed into it and puts it into various forms, including charts and maps to send back to the kids. Back in their classrooms, students analyze patterns and trends in their data and compare their results with kids in other schools across the nation.

The developers of the project believe that students will be learning several important messages about how science is conducted. They'll learn that measurement is essential, that science is cooperative, that everyone can participate, and that scientific inquiry and the results of that inquiry matter. According to Robert Tinker, director of the project, "It is conceivable that students will discover something new through the network experiments and likely that their measurements will be similar to those of professional scientists."

In describing pilot test results of their acid rain unit, Tinker reports that, "the students puzzled over their measurements and wondered why Nebraska had such an unexpectedly high level of acid rain . . . Students became engrossed in finding out more about the communities where the other sites were located. They learned valuable lessons about the process of science, engaged in spirited discussions about scientific method, the validity of data, and the need for care in measurement . . . teachers enjoyed teaching it, and, in Nebraska, vowed to develop additional units even if funding did not materialize." Results of the first-year effort are currently being analyzed and plans are underway to continue testing in up to 1,000 sites across the country.

More Science Networking

Another science project using electronic communications is being tested by sixth-grade students and teachers in Manhattan.[53] This project, called

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52. Robert Tinker, "Network Science Arrives," Hands On!, vol. 10, No. 1, (Cambridge, MA: Technical Education Research Centers, 1987).
53. David Newman, et al., Earth Lab: Progress Report, (New York, NY: Bank Street College of Education, 1987).

Earth Lab, is intended to allow students to collect, analyze, share and write about their own science research projects in geographic systems, such as convection, the water cycle, and weather forecasting. Earth Lab is designed for teachers who have little or no prior experience with computers or the complexities of science as practiced in the real world. Developed by researchers at the Bank Street College of Education's Center for Children and Technology, Earth Lab involves several ways to use the computer to get work done, including a word processor to record interviews, an electronic mail system that students can use to send teachers hypotheses about their data, and a data base program to record and analyze the data they collect in the weather station.

Bank Street researchers interviewed teachers and observed the implementation of the school's science program both before and after the introduction of Earth Lab. Early results show that there was a "tremendous amount of change in the way planning, organization, and coordination of the science education program in the school has taken place as a result of using Earth Lab." (p. 12). Teachers seemed more interested in science, taught more science classes and worked together to coordinate efforts among classroom teachers, computer lab teachers and science teachers. Teachers also used the electronic network to communicate with each other about lesson plans and classroom activities. The researchers also noted more integration of science content into reading, language arts and social studies. Studies of Earth Lab are still in progress.

Support for Rural Teachers

Teachers located in the remote rural areas of New England are using electronic networks to discuss the issues and problems they face in teaching science. The Educational Technology Center at Harvard University has organized and is studying a network designed to encourage professionally isolated teachers to pose and respond to each other's questions about science instruction and to participate in discussions originated by "guest" scientists and educators.

Early results indicate that more isolated teachers use the network more frequently, and that all teachers found the information they had obtained through the network to be valuable. The researchers reported that one of the major barriers to participation was access to a computer. If teachers had a personal computer at home, they were more apt to participate.

Summary. Tyson attributes some of the enthusiasm for electronic networks to a writer's need for sense of audience -- "Poor writers usually lack the sense that they are writing to make something clear and enjoyable to others."[54]

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54. Harriet Tyson, S. Shafto & J. Capper, "Computers and Writing Instruction," Teaching, Learning and Technology, vol. 1, No. 2, Washington, DC: Center for Research into Practice, in press.

Schools have fostered this lack of audience by having the teacher be the only prospective reader. When students write for each other, edit one another's work, and are forced to make their prose clear to even an unseen student in another school, state or country, they think more deeply about meaning and work harder to see themselves through the eyes of the intended readers.

Comprehension Assistance Programs

Current reading theory assumes that comprehension is an interaction of a number of cognitive subprocesses including decoding, word recognition, and knowledge-dependent processes. If a reader is deficient in one or more of these subprocesses, then the rest of the reading system will not be completely available when needed. And, if one aspect is particularly demanding, then the reader may not be able to attend to other essential subprocess. [55, 56]

For example, in reading science textbooks, there are a large number of long, unfamiliar and technical words that are, at first, completely unfamiliar to students. In fact, Rowe contends that the typical middle school science textbook contains 2,500 words, sometimes as many as 15 new words per page -- more new language than one finds in the first year of foreign language study.[57] Many students find the comprehension of these technical words so demanding, they are unable to attend to the other subprocesses needed to make sense of science texts.

Early instruction in reading typically attends to developing proficiency in the various subprocesses. The goal of many instructional events is to automatize cognitive subprocesses so that the learner is able to devote more intellectual work to higher levels of thinking. [58, 59, 60, 61]

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55. Charles Perfetti, Reading Ability. (New York: Oxford Univ. Press, 1985).
56. Steven F. Roth and Isabel L. Beck, "Theoretical and Instructional Implications of the Assessment of Two Microcomputer Word Recognition Programs," Reading Research Quarterly, vol. 22, 1987, pp. 197-218.
57. Mary Budd Rowe, "Getting Chemistry Off the Killer Course List," Paper presented at the American Chemical Society Meeting, Las Vegas, 1982.
58. Charles Perfetti and T. W. Hogaboam, "The Relationship Between Single Word Decoding and Reading Comprehension Skill," Journal of Educational Psychology, vol. 67, 1975, pp. 461-469.
59. Charles A. Perfetti and Alan Lesgold, "Discourse Comprehension and Sources of Individual Difference," In M. A. Just and P.A. Carpenter (eds.), Cognitive Processes in Comprehension (Hillsdale, NJ: Erlbaum, 1977), pp. 141-183.
60. Charles A. Perfetti and Alan Lesgold, "Coding and Comprehension in Skilled Reading and Implications for Reading Instruction," In Lauren B. Resnick & P.A. Weaver (eds.), Theory and Practice of Early Reading, vol. 1, (Hillsdale, NJ: Erlbaum, 1979), pp. 57-84.
61. J. R. Frederiksen, A Chronometric Study of Component Skills in Reading. Tech. Report. No. 2 (Cambridge, MA: Bolt Beranek and Newman) 1978.

In addition, research has shown that comprehension occurs only when the reader actively processes the text. Also important to comprehension is the reader's ability to manage his or her comprehension. The deliberate and conscious control over one's own cogntive processes is referred to as metacognition. It involves being aware of ones' strengths and weaknesses in learning, knowing what the demands of the task are, and what should be done if comprehension is suffering.

Thus, reading interventions, both with and without computers, aim at one or all of these three major aspects of reading comprehension: improving performance on the subprocesses, improving comprehension monitoring strategies (metacognition), or increasing the liklihood that students will cognitively interact with the text.

In a review of reading and writing courseware, Russ-Eft reported that because the computer medium is not as directly related to the subject matter of reading as it is to math and science, the vast majority of software packages focus on the simplest of tasks -- spelling and vocabulary.[62] Collins called most reading courseware conceptually indigent, offering exercises in mechanisation and artifical memorization.[63] A 1982 analysis of 317 reading and writing programs showed that 60 percent were concerned solely with drill and practice and only two dealt with whole texts.[64] In a review of educational programs listed in a 1980 catalogue, Rubin reported that nine of the 105 reviewed required the student to manipulate text at the letter level, 85 required the student to work with isolated words, seven involved the student in dealing with phrases or sentences, and only seven programs presented students with whole text.[65]

More recently, there has been progress in the design and production of courseware that incorporates the latest theoretical views of learning to read with the unique advantages offered by the computer.

Decoding and Word Recognition Programs

Roth and Beck, developed two computer programs designed to improve the reading comprehension of low-achieving fourth-grade students by increasing both their speed and accuracy of decoding and their word-recognition skills.

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62. Darlene F. Russ-Eft, "Reading and Writing: Ideas for Courseware Development and Research," Presented at the American Educational Research Association, New Orleans, LA: 1984.

63. Allen Collins, Teaching Reading and Writing with Personal Computers, (Cambridge, MA: Bolt, Beranek and Newman, Inc., 1985).

64. H. Brugelmann, "Microcomputers and the Acquistion of Literacy: An Educational Miracle or a New Monster in the Nursery?," Report No. 20, (Bremen University, 1985).

65. Andee Rubin, "The Computer Confronts Language Arts: Cans and Shoulds for Education," in Alex C. Wilkinson (ed.), Classroom Computers and Cognitive Science, (New York, NY: Academic Press, 1982).

Research has shown a direct, positive correlation between decoding and word recognition and reading comprehension.[66] One program, called Construct-A-Word (See Figure 5), involved students in composing words from sets of sub-word letter strings.[67] Another program, Hint and Hunt (HH), is designed to increase the accuracy and efficiency with which vowels and vowel combinations (digraphs) are used to identify words.[68] According to Roth and Beck, there is evidence that the most difficult portion of words is in the middle, which in single-syllable words contain the vowel.[69, 70]

Roth and Beck studied 108 low-achieving, low-SES black children who used the computer programs for 20 to 24 hours over a 20 week period. Results showed that students who used the programs outperformed a control group in accuracy and efficiency of decoding and word recognition skills. In addition, the decoding improvements generalized to similar activities provided in different forms from the instruction. The effects were not limited to the specific words contained in the instruction. The improvements for low-ability students were substantial -- they gained over a year on standardized tests, but students who were already adequate in their decoding skills did not show any changes. The findings were essentially the same for the development of students' ability to comprehend phrases and sentences. There were no improvements, however, at the passage level of comprehension, suggesting that other components of reading need to be addressed before comprehension is achieved at the text-discourse level.

Text Mediation Programs

Reinking and Schreiner tested the hypothesis that a computer would be able to mediate the presentation of textual material so that students could interact with the text to serve their individual comprehension needs.[71] They developed a computer program that allowed students to

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66. Steven F. Roth and Isabel L. Beck, "Theoretical and Instructional Implications of the Assessment of Two Microcomputer Word Recognition Programs," Reading Research Quarterly, vol. 22, 1987, pp. 197-218.

67. Isabel L. Beck and Steven F. Roth, Construct-A-Word (Allen, TX: Developmental Learning Materials, 1984a).

68. Isabel L. Beck and Steven F. Roth, Hint and Hunt (Allen, TX: Developmental Learning Materials, 1984b).

69. A. Biemiller, "The Development of the Use of Graphic and Contextual Information as Children Learn to Read," Reading Research Quarterly, vol. 6, 1970, pp. 75-96.

70. R. Weber, "A Linguistic Analysis of First-grade Reading Errors," Reading Research Quarterly, vol. 5, 1970, pp. 427-451.

71. David Reinking and Robert Schreiner, "The Effects of Computer-mediated Text on Measures of Reading Comprehension and Reading Behavior," Reading Research Quarterly, vol. 10, No. 5, 1985, pp. 536-551.

Figure 5
Example of *Construct-A-Word* screen

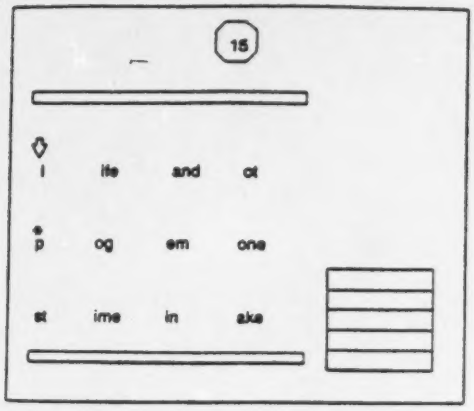
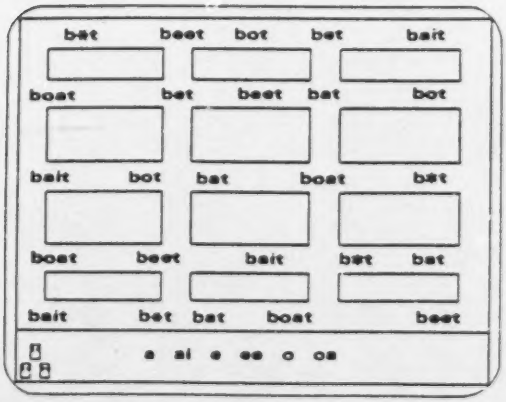


Figure 5a
Example of *Hint and Hunt* screen



obtain: 1) definitions of key vocabulary, 2) a paraphrase or less technical version of the content, 3) supplemental background information or illustrations, and/or 4) some representation of the content's structure. Prior research has found that each of these activities helps readers to generate meaning from difficult text.[72, 73, 74, 75, 76, 77]

Reinking and Schreiner then conducted a study whereby students read selected passages on the computer. One group read passages in traditional text form, another read the same passages on the computer, but without access to the forms of comprehension assistance listed above, a third group could receive one or all of the forms of assistance upon request, and the fourth group received all four forms of comprehension assistance whether they asked for it or not.

The findings showed that students who received all four forms of comprehension assistance without asking for assistance performed better than the other three groups. However, poor readers who read low-difficulty passages from the text only, performed significantly better than did students who read on the computer and could select comprehension assistance options.

Reinking and Schreiner interpret these results by suggesting that, because intermediate-grade readers are less adept at managing the contingencies of their reading, they benefited from the external control provided by the computer. Providing the comprehension options may have encouraged readers to process the meaning of the text more deeply.

Speech Synthesizers

More recently, computers have been paired with speech synthesizers to assist both regular and special education students in understanding words or parts of words.

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72. Robert C. Anderson and P. Freebody, "Vocabulary Knowledge," in J.T. Guthrie (ed.), Comprehension and Teaching: Research Reviews (Newark, DE: International Reading Association, 1981), pp. 77-117.

73. E. B. Coleman, "Developing a Technology of Written Instruction: Some Determiners of Complexity of Prose," in E. Z. Rothkopf and P .E. Johnson (eds.), Verbal Learning Research and the Technology of Written Instruction (New York: Columbia University, Teachers College Press, 1971) pp. 155-204.

74. C. Filmore, "The Case for Case," in E. Bach and K. Harms (eds.), Universals of Linguistic Theory (New York: Holt, Rinehart & Winston, 1968), pp. 42-85.

75. J. Grimes, The Thread of Discourse (The Hague: Mouton, 1975).

76. W. Kintsch and T. van Dijk, "Toward a Model of Text Comprehension and Production," Psychological Review, vol. 85, 1978, pp. 363-394.

77. B. J. F. Meyer, The Organization of Prose and Its Effect on Memory (Amsterdam: North-Holland Publishing, 1975).

Several systems in use with learning disabled readers involve individuals reading text displayed on the computer screen and "telling" the computer when they encounter a word they don't understand. They do this by touching the word on the screen with a light pen or a mouse. The computer has been programmed to then tell the student what the word is, either through an audio recording of the word through the student's earphones or by a speech synthesizer built into the computer.

According to Olson, most disabled readers are uniquely deficient in phonetically decoding or "sounding out" unfamiliar printed words.[78] This typically results in a reading vocabulary that develops substantially slower than students' oral vocabularies. What these systems contribute is to allow people with poor reading skills to read passages that are beyond their independent reading level. The computer is providing the mediation that would otherwise be provided by a teacher, parent or tutor.

There are several virtues of computer-aided reading using speech feedback for decoding difficulties: 1) disabled readers can conveniently and privately receive the decoding help they need without the labor intensity of an individual human tutor or teacher, 2) speech feedback can be tailored to match the unique needs of each student, 3) a wider variety of reading materials can be used, 4) reading can become a means for gaining knowledge, 5) the amount of actual time spent reading is maximized because the reader/student doesn't have to wait for the teacher to explain an unknown word or spend lengthy periods trying to identify difficult words 6) students are more likely to experience a feeling of success as they progress through the material and easily gain knowledge of new words and increased information from the passages, and 7) the computer maintains a detailed record of the student's reading and requests for assistance, thereby providing researchers with useful information for the study of comprehension problems.[79]

Several studies of computer-aided reading using a speech synthesizer have been conducted, all with limited but positive results. Olson studied the impact of computer-aided reading on 26 reading disabled students between the ages of 8 and 18. The students read passages at varying levels of difficulty and were instructed to target words they did not recognize. The findings showed that the students enjoyed using the system and showed significant short-term gains in word recognition and comprehension when speech feedback was available.[80,81]

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78. R. Olson, "Disabled Reading Processes and Cognitive Profiles," in Gray and Kavanagh (eds.), Biobehavioral Measures of Dyslexia, (Parkton, MD: York Press, 1985), pp. 215-243.

79. George W. McConkie, et al., "Computer Aided Reading with Illiterate Adults," unpublished paper, 1987.

80. R. Olson, et al., "Reading Instruction and Remediation with the Aid of Computer Speech," Behavior Research Methods, Instruments and Computers, vol. 18, No. 2, 1986, pp. 93-99.

81. R. Olson & B. Wise, "Computer Speech in Reading Instruction," in D. Reinking (ed.), Computers and Reading: Issues for Theory and Practice (NY: Teachers College Press, 1987).

McConkie and Zola used the system in adult education courses with some of the participants enrolled to learn English-as-a-second-language. Although this was only a preliminary, pilot test in which a number of equipment break-downs occurred, the participants and teachers both expressed great enthusiasm for the computer-aided reading system, with interest growing as time went by. Many of the ESL students used the system to test out their pronounciation of English words, repeatedly listening to a word and then speaking it softly. [82]

In another pilot study, six students, also enrolled in an adult education center, were observed individually and interviewed by researchers as they used the system. The researchers asked the participants to alternate reading the passages with and without the use of the speech feedback. One of the more interesting findings was that use of the speech feedback significantly reduced the level of stress the participants exhibited when struggling with reading in the unaided situation. The participants commented about how hard it was to read and asked if they had to continue. The researchers reported that much of the stress disappeared when they used the speech feedback. The students all indicated that it was much easier to read when they had the assistance and inquired if it were possible to obtain such a system for their personal use and for use by their children or spouses. In addition, many students indicated that they would read more if such a system were available.

Zola also used a Computer-Aided Reading program with seventh grade students whose IQ scores ranged from 80-99 and reading scores were at least two years below grade level. In this study, the treatment students read social studies content on the computer, with the assistance of speech feedback, while the control students spent the 20-25 minute period in the social studies class. Results showed that the experimental students significantly outperformed the control students on a comprehension monitoring test (detection of inconsistencies in a passage), and showed slight, but not significant gains on the test of content knowledge. All of the experimental students indicated that they would prefer to have the computer's assistance and felt that it helped them to understand the textbook and in their classwork. [83]

Teachers indicated that some of the students seemed to have gained confidence in their reading and were more willing to volunteer information or answer questions in class. They also indicated that if they had access to such a system on a regular basis they could spend less class time reading the text with students and more time in discussions.

Staff at the Houston Independent School District used speech synthesizers in their locally-developed computer courseware designed to assist limited-English-proficient students in learning English vocabulary and grammar. The dis-

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82. George W. McConkie and David Zola, "Computer Aided Reading: An Environment for Developmental Research," Paper presented at the Society for Research on Child Development, Toronto, Canada, 1985.

83. D. Zola, "Final Report of Phase I Project," submitted to the Public Health Service, 1986.

trict resorted to developing their own computer-based instructional system when they were unable to identify commercially-developed materials suitable for their 34,000 limited English proficient students. The resulting courseware incorporates dynamic, high resolution graphics and digitized speech within a variety of simulation and game programs and is intended for use by students in kindergarten through fifth grades.

According to the developers, "The use of digitized speech has added a new dimension to this courseware. The ability to hear human speech as a language model has revolutionized this second language learning courseware. The high quality of speech makes it possible for the students to listen to the phrases and sentences and repeat the material."

Results of an evaluation of one of the 14 units showed that the treatment group scored significantly better than did control students.[84] The courseware is now being published commercially.

One of the most widely marketed computer-based educational programs using digitized speech is IBM's Writing to Read. It is a multi-component system involving kindergarten and first grade children in typing words, reading while listening to tape-recorded stories, and listening to computerized speech designed to teach basic phonics rules.

Writing to Read is characterized as a language experience program that teaches children to read through their own writing. Children move through workstations set up throughout a classroom, engaging in specific tasks at each station. At the computer station they learn the constituuent sounds of words (phonemes) and how these sounds can be combined to form words. The Work-Journal station provides children with the opportunity to print on paper the letter combinations that represent the phoneme learned at the computer. At the Writing/Typing station, they write or type their own stories and thoughts in their own language patterns, relying on the phonemic spelling system learned at the computer. The Listening Library station involves children in reading stories along with a tape recording of the story, in part to help them become familiar with book spelling (often different than phonemic spelling in the English language). The final station, Make Words, engages students in putting together and taking apart words to learn the letters that represent phoenemes. Writing to Read is a completely individualized program allowing children to learn to read and write at their own pace and in their own way.[85]

The evaluation of Writing to Read was one of the most comprehensive studies conducted at the kindergarten and first grade levels. A nationwide sample of 35 Writing to Read schools and 25 Non-Writing to Read schools was assessed, representing over 200 teachers and 7,000 children. Writing, reading and spelling skills were measured.

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84. Jean Anderson, English as a Second Language Courseware Product Evaluation Report, (Houston, TX: Houston Independent School District, 1985).

85. Dale M. Willows, Writing to Read as a New Approach to Beginning Language Arts Instruction: An Education Consultant's Report (IBM Canada Ltd., 1986).

The results showed that the Writing to Read students performed significantly better in writing than the control students in both kindergarten and first grade (Table 1). Writing to Read students in the first grade a year after having had the program still outperformed non-Writing to Read students, but the differences between the two groups narrowed substantially. In fact, while the non-Writing to Read scores increased over the year, the Writing to Read scores decreased slightly. Classroom observations revealed that students were delighted with their writing and eager to read their passages aloud to visitors.[86]

Table 1
Mean Writing Scores by Group
(percent)

Group	Writing to Read	Non-Writing to Read
Kindergarten	4.5	3.1
First Grade	6.6	4.9
First Grade After Writing to Read	6.5	5.7

From Murphy and Appel, 1984

The results for reading were less impressive. Children in both the non-Writing to Read and the Writing to Read program progressed faster than their corresponding norm groups on standardized achievement tests. The improvement of both groups was about the same.

Spelling was assessed in a less systematic fashion, but results showed that the performance of both groups was quite similar. Writing to Read did not appear to have a negative affect on students' spelling.

A survey of teachers showed that Writing to Read teachers rated the program far more effective for above average students than for average or below-average students.

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86. Richard T. Murphy and Lola Rhea Appel, "Evaluation of the Writing to Read Instructional System 1982-84. (Princeton, NJ: Educational Testing Service, 1984).

Unfortunately, the study suffered from a problem found in several other studies described in this chapter -- the Writing to Read students spent more time in reading instruction than did the control groups.[87] A larger percentage of teachers involved in the Writing to Read program reported spending more time on reading instruction than in previous years (58.2%), than did the non-Writing to Read teachers (26.7%). In writing, 80.5% of the Writing to Read teachers indicated that they spent more time on writing than in the previous years as compared with 30.5% in the non-Writing to Read classrooms. On the one hand, any program that engages kindergarten and first-grade children in writing activities is desirable, but the positive effects found in the program may be attributable to increased time rather than to any aspect of the Writing to Read program.

Spelling Instruction Programs

Researchers at Vanderbilt's Learning Technology Center have shown that the speech synthesizer can be useful in providing effective spelling instruction. Traditional approaches to spelling instruction involve the teacher in saying the word, having students write the word and then checking the written word against the correctly spelled word. Some computerized approaches involve students in typing the word from a model on the screen and then typing the same word after the model is removed and then entering the word into a sentence. Most studies using variations on this instructional theme have shown either no significant difference between computer and non-computer groups and/or limited success with either group.[88, 89, 90]

Hasselbring argue that these approaches were unsuccessful because the student could rely on spelling the word by engaging only short-term memory; they did not need to commit the spelling of the word to long-term memory.[91]

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87. Richard Olson and Barbara Wise, "Computer Speech in Reading Instruction," in David Reinking (ed.), Computers and Reading: Issues for Theory and Practice (New York, NY: Teachers College Press, 1987).

88. G. Fitzgerald, et al., "Computer-assisted Instruction for Students with Attentional Difficulties," Journal of Learning Disabilities, vol. 19, No. 6, 1986, pp. 376-379.

89. P. A. McDermott and M. W. Watkins, "Computerized vs. Conventional Remedial Instruction for Learning-disabled Pupils," Journal of Special Education, vol. 1, No. 1, 1983.

90. Jacqueline Haynes, et al., Effect of Computer-assisted Instruction on Learning Disabled Readers' Metacognition and Learning of New Words, Research report #101, (College Park, MD: Univ. of Maryland, Institute for the Study of Exceptional Children and Youth, 1984).

91. Ted Hasselbring, et al., "A Comparison of Computer and Human Feedback on the Spelling Performance of Learning Handicapped Students," submitted for publication, 1987.

Short-term memory refers to a capacity for keeping a limted amount of information in a special active state. Anderson suggests that short-term memory holds only knowledge currently in use and thus represents a limitation on our mental capacity. Long-term memory refers to a large body of information that is relatively permanently encoded. While information is forgotten from both, it is forgotten at a much slower rate in long-term memory. [92]

Hasselbring and his colleagues investigated presenting the spelling words to students by using a voice simulator. The primary difference between this approach and traditional approaches is that students do not see a visual model of the word, so cannot rely on their short term memory. To remember the word, they must activate their long-term memory. In addition, when the student spells the word incorrectly, the computer visually and auditorially imitates the student's error followed by the correct spelling so that the student can compare the two. Results of studies using this approach show that students achieve an accuracy of over 90 percent on lists of spelling words and that the computer group averaged over 30 percent more correctly spelled words than when the same group used traditional procedures. [93]

Limitations of Software Review Checklists

These results highlight the importance of conducting research or evaluation studies on software used in classrooms. The common checklist procedures used in typical software reviews may lull educators into thinking that they have a piece of software that is educationally sound because it meets criteria such as the following: 1) content is appropriate for intended student population, 2) content is accurate, 3) content is free of grammar, spelling, punctuation and usage errors, 4) definitions are provided when necessary, 5) there is continuity between information presented and prerequisite skills required, etc.

For example, Hasselbring argues that there is no evidence to suggest that practice in unscrambling words or typing a word flashed on the screen will lead to improved spelling. However, educators using checklists with criteria such as those listed above may give a high rating to such a piece of software, when in fact it does not really accomplish its intended purpose. An additional risk is the temptation to blame the students or teacher when students fail to learn from a piece of software.

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92. John R. Anderson, Cognitive Psychology and Its Implications (San Francisco, CA: W.H. Freeman & Company, 1980)

93. Ted Hasselbring, "Remediating Spelling Problems in Learning-handicapped Students Through the Use of Microcomputers," Educational Technology vol. 22, 1982, pp. 31-32; and "Using a Microcomputer for Imitating Student Errors to Improve Spelling Performance," Computers, Reading and Language Arts vol. 4, 1984, pp. 12-14; see also "Effective Computer Use in Special Education: What Does the Research Tell Us?" Presented at Funder Forum, sponsored by Apple Computer, Inc. Cupertino, CA: 1987.

Programming and Mathematics

For over 25 years, mathematics educators have advocated the use of programming for teaching mathematics.[94, 95, 96, 97] The rationale for this recommendation is that "Children who program solutions to science and mathematics problems develop a procedural understanding of the fundamental theories of these disciplines." (p. 1).[98] In other words, in order to write a program for something (an algorithm in mathematics), the student must complete a careful analysis of the problem.

Students also attest to the value of programming in learning to solve mathematics problems. High school students who learned to apply programming to numerical sequences and various iterative methods for solving quadratic equations, responded: "I've gotten much better at problem solving . . . I think the most helpful (idea) has been breaking things down into steps. I find myself doing that now -- trying to figure out where to start and what to do next." (p. 42). Another student stated that she, ". . . learned a lot about the computer and how to solve equations. I did more algebra in here than I did all last year." (p. 51).[99]

But, does the research evidence support the use of programming to teach mathematics? First, we should note an interesting, but unexplainable trend in this body of research. While most of the studies that have been done were conducted in the early 1970's, very few studies have been conducted over the past 15 years. This is peculiar since most of the early studies either showed negative or inconclusive results. There have, however, been an increasing number of studies looking at the relationship between learning to program and the development of students' analytical thinking and problem solving abilities. This body of research will be discussed in the next section.

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94. National Council of Teachers of Mathematics, The Impact of Computing Technology on School Mathematics: Report of an NCTM Conference, (Reston, VA: NCTM, 1984).

95. National Research Council, Renewing U.S. Mathematics, (Washington, DC: National Academy Press, 1984).

96. Conference Board of the Mathematical Sciences, The Mathematical Sciences Curriculum K-12: What is Still Fundamental and What is Not, Report to the National Science Board Commission on Precollege Education in Mathematics, Science and Technology, (Wash., DC: National Science Foundation,1983).

97. Richard J. Shumway, "Mathematical Concept Learning through Computer Programming: A Survey of Related Research," prepublication draft, Ohio State University, 1985.

98. Sylvia A. Shafto, "Programming for Learning in Mathematics and Science," Paper presented at a Conference on Innovative Microcomputer Applications in School Programs, Friends School in Baltimore MD: March 1985.

99. Mary K. Prichard, "Student Programming as a Context for Developing Mathematical Concepts," Paper presented at the Research Presession of the Annual Meeting of the NCTM, San Antonio, TX, 1985.

With regard to using programming to teach mathematics at the elementary - middle school level, two of four studies showed that students who did not use programming outperformed those who did. The remaining two studies found partial and limited support for programming. At the high school level four studies found that students who received programming instruction in addition to mathematics instruction performed less well than did students without programming instruction.[100, 101, 102] Two studies found partially positive results.[103, 104] College-level studies were somewhat more encouraging with three of four studies showing positive effects.[105, 106, 107]

du Boulay used programming to prepare student teachers to teach mathematics facts and concepts. His observations pinpoint the essential difficulties for both teachers and students: 1) students who have problems learning mathematical concepts are likely to find programming concepts equally elusive, 2) additional and more complex cognitive effort is involved in establishing a connection between programming and mathematics, and 3) learning to program requires a great deal of time -- time that could be devoted to learning mathematics.[108]

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100. D. F. Robitaille, et al., "The Effect of Computer Utilization on the Achievement and Attitudes of Ninth-Grade Mathematics Students," Journal for Research in Mathematics Education, vol. 8, 1977, pp. 26-32.

101. D.T. King, "Research on Computers in Mathematics Education," The Use of Computers in Mathematics Education Resource Series," (Columbus, OH: ERIC, 1973).

102. S. M. Katz, "A Comparison of the Effects of Two Computer Augmented Methods of Instruction with Traditional Methods Upon Achievement of Algebra Two Students in a Comprehensive High School," Doctoral Dissertation, (Temple University, 1971, DAI, 1188-A, University Microfilm, No. 71-19,986, 1971).

103. R. F. Ronan, "A Study of the Effectiveness of the Computer When Used as a Teaching and Learning Tool in High School Mathematics," Doctoral dissertation, (University of Michigan, 1971, DAI, 32, 1264-A, Univeristy Microfilms No. 71-23, 861, 1971).

104. Larry L. Hatfield and Tom E. Kieren, "Computer-assisted Problem Solving in School Mathematics," Journal for Research in Mathematics Education, vol. 3, 1972, pp. 99-112.

105. Frederick H. Bell, "A Study of the Effectiveness of a Computer-oriented Approach to Calculus," an unpublished doctoral dissertation, Cornell University, (DAI, 31'3, p. 1096-A, 1970).

106. Gary G. Bitter, "Effect of Computer Applications on Achievement in a College Introductory Calculus Course," unpublished doctoral dissertation, (University of Denver, 1970).

107. M. O. Holoien, "Calculus and Computing: A Comparative Study of the Effectiveness of Computer Programming as an Aid in Learning Selected Concepts in First-Year Calculus," unpublished doctoral dissertation, (University of Minnesota, 1970).

108. J. B. H. duBoulay, "Teaching Teachers Mathematics Through Programming," International Journal of Mathematical Education in Science and Technology, vol. 11, 1980, pp. 347-360.

Nevertheless, the idea is conceptually appealing and has the support of the mathematics education profession. Further research is defensible, but perhaps should proceed along different theoretical lines from earlier research. Blume recommends a cognitive approach that attempts to clarify the specific effects that programming has on various algorithmic and heuristic processes, as well as other cognitive competencies such as metacognition and creativity. He also advocates that individual students be the focus of study before attempting to study the effects of programming in classrooms. Questions that should be asked include: Does programming help students to understand, describe, represent or sequence a problem? Does it promote planning and checking strategies? If so, under what conditions?[109]

Shafto recommends that instruction in programming begin in kindergarten or first grade, where students would learn very simple programming commands that apply to the math and science concepts appropriate for their age group. In addition, she suggests that programming be taught over a period of eight to ten years, rather than as a separate topic. In that way, students become accustomed to programming gradually and see its application in a wide variety of settings. Moreover, teachers only need to learn the amount of programming necessary to teach concepts appropriate to their level of instruction.

In summary, while enthusiasm is high for using programming to develop students' procedural understanding of the fundamental theories of math and science, the evidence to support this application is inconclusive. Future research should focus on the cognitive processes involved in using programming to teach mathematics and science, and studies of long-term, systematically integrated approaches merit investigation.

In the discussion above, programming is intended to be used as a tool to facilitate the learning of traditional subject matter. However, most of the programming that has been taught in schools has been to either enhance students' employment opportunities after graduation, or to develop their problem solving and analytical thinking abilities.

Programming and Employability

Neither assertion is strongly supported by research evidence. Researchers at the National Commission for Employment Policy conducted a study to examine the need for computer skills in the workforce and concluded that only about one percent (1%) of the workforce will require long periods of computer training (e.g., engineers and scientists who design computers, programmers, systems analysts, etc.). Another one percent (1%) will need to be able to write their own programs (e.g. some engineers, scientists, technicians, accountants). The remaining computer users will learn their skills in brief, on-the-job training.

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109. Glendon W. Blume, "A Review of Research on the Effects of Computer Programming on Mathematical Problem Solving," Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, 1984.

Goldstein and Fraser suggest that computer-related training need not be part of the general curriculum but should be part of a total training package for occupations that require computer use.[110]

Programming and Thinking

Evidence to support the belief that programming develops students' thinking abilities is limited and mixed. Ford found that students who learned BASIC did no better than control students on three problem-solving subtests: understanding the problem, carrying out the plan, and looking back at the problem.[111] Pea and Kurland also found that students who spent a year programming did not differ from control students in planning efficient routes for completing a set of chores.[112]

Positive results were found by Schwartz, Evans & Caritj who conducted a large-scale Logo study in 15 schools over 7 months. The Logo students showed significantly more improvement than did non-Logo students on a test of nonverbal cognitive abilities and exhibited less reliance on their teachers and showed more independent judgment.[113]

Statz found that 9 to 11 year-old students who received a year of instruction in Logo performed significantly better than control students on two of four problem-solving tasks.[114] In another study of 18 six-year-olds, students who recieved 12 weeks of instruction in Logo outperformed students who used the computer to study reading and mathematics in a CAI environment. Students were assessed on measures of creativity, meta-cognition (ability to monitor and evaluate one's own thinking processes), and on their ability to provide accurate descriptions -- an important skill in programming. The two groups did not differ on general measures of cognitive development.[115]

110. Harold Goldstein and Bryna S. Fraser, Training for Work in the Computer Age: How Workers Who Use Computers Get Their Training (Washington, DC: National Commission for Employment Policy, 1985).

111. M. Ford, "Effects of Computer Programming on the Problem Solving Abilities of Sixth Grade Students," unpub. dissert., Ariz. State Univ., 1984.

112. Roy D. Pea and D. Midian Kurland, Logo Programming and the Development of Planning Skills, Technical Report No. 16, (New York, NY: Center for Children and Technology, Bank Street College of Educ., 1984).

113. T. A. Schwartz, et al., "Looking Into a Large-Scale Logo Project," Paper presented at the annual meeting of the American Educational Research Association, New Orleans, 1984.

114. Joyce Statz, "The Development of Computer Programming Concepts and Problem Solving Abilities Among Ten-Year-Olds Learning Logo," (Doctoral Dissertation, Syracuse University, 1973, DAI, 34, 5418B-5419B, University Microfilms No. 74-10, 1800, 1973).

115. D. Clements and D.F. Gullo, "Effects of Computer Programming on Young Children's Cognition," J. of Educational Psychology, vol. 76, No. 6, 1984.

A number of researchers have studied the instructional aspects of learning to program and have found that several ingredients are important to a successful learning experience. First, a substantial amount of time needs to be devoted to programming instruction if one is to expect any amount of competence. In fact, many of the studies described above may have failed to obtain positive results due to insufficient instructional time.

Kurland and Cahir compared the amount of time that computer experts spent learning to program with the amount typically found in elementary and secondary courses and found quite substantial differences. The "experts" indicated that they devoted enormous amounts of time in learning to program, with estimates averaging from 20 to 35 hours a week. One software game designer described her college experience: "One semester in school I think I averaged about four hours of sleep a night for three months. My health was damaged, my brain was damaged. I don't think I could go for more than three days without total collapse." (p. 11).[116]

In contrast, Becker found that the typical amount of time secondary students spend learning to program in a year is only as much as the "experts" in Kurland and Cahir's study claimed to have spent in a single week.[117] It is unlikely, then that we can expect to accrue the desired effects of learning to program without evidence that students have indeed learned to program.

Researchers have also looked at how students learn to program and report that they often have misconceptions of programming terms and functions. These researchers are looking for ways to improve programming instruction and suggest that in addition to substantially more instructional time, students should devote more time to learning and applying design skills as opposed to time spent learning the language features of programming. Language features refer to the various commands involved in programming, such as PRINT or READ. Design skills allow students to invent and refine programs and include learning templates and procedural skills such as planning, testing, and revising.

In summary, there is not yet sufficient evidence to support teaching students to program. Very few jobs actually require or use programming skills and the cognitive benefits are still in question. Factors such as insufficient instructional time, inappropriate instructional strategies, and inadequate measures may mask the cognitive outcomes that programming is intended to elicit.

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116. D. Midian Kurland and Nancy Cahir, The Development of Computer Programming Expertise: An Interview Study of Expert Adult Programmers. (New York, NY: Center for Children and Technology, Bank Street College of Education, 1984).

117. Henry J. Becker, School Uses of Microcomputers: Reports from a National Survey, Issues 1-6, (Baltimore, MD: Center for Social Organization of Schools, Johns Hopkins University, 1983- 1984).

Computer-Assisted Instruction

Computer-assisted instruction (CAI) has been the most frequently used and researched computer application in education.[118] For almost 30 years, computers have been used to provide instruction or drill and practice in basic skills (e.g., computation or letter recognition).

Early CAI programs (from 1963 to 1980) were provided through large main-frame, time-sharing computer systems, that were operated and controlled from a central location. Examples of such systems include PLATO (Programmed Logic for Automatic Teaching Operations), created at the University of Illinois, and Stanford University's CAI project for elementary reading and mathematics skills. Most of these programs were developed for use at the elementary level, primarily in reading and mathematics. In 1982, personal microcomputers were introduced into schools and, in many cases, have replaced reliance on the large, time-sharing systems.

There are several issues surrounding the use of mainframe systems versus personal computers for instruction. Because mainframes are powerful systems with large memories, they can accommodate comprehensive and integrated curricular programs that span several grade levels and many skill areas. In addition, mainframe systems can store large amounts of information on students' responses to test items and can provide both students and teachers with profiles of student performance in the curricular area. Mainframe systems are considerably more costly than personal computers and, therefore, leave districts with less flexibility in configuring a package of computers for instruction. And because the curricular package is more comprehensive, the quality of that package is more salient than when purchasing a single program for use on a personal computer. Use of mainframe systems also transpose much of the instructional decision making from teachers to curriculum developers.

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118. P. K. Burns and W. C. Bozeman, "Computer-assisted Instruction and Mathematics Achievement: Is There a Relationship?," Educational Technology, October 1981; and Joanne Capper and Carol Copple, "Computers in Education: Research Review and Instructional Implications," The Research into Practice Digest, vol. 1, No. 3, Spring 1986; also J. F. Vinsonhaler and R. K. Bass, "A Summary of the Major Studies on CAI Drill and Practice," Educational Technology, vol. 12, 1972; and Dean Jamison, et al., "Cost and Performance of Computer-Assisted Instruction for Education of Disadvantaged Children," in J. Froomkin, et al., (eds.), Education as an Industry, (Cambridge, MA: Ballinger Publishing Company, 1976); and J. Edwards, et al., "How Effective is CAI? A Review of the Research," Educational Leadership, vol. 33, 1975; and S. S. Hartley, "Meta-analysis of the Effects of Individually Paced Instruction in Mathematics," Doctoral Dissertation, University of Colorado, 1977). DAI, 38 (7-A), 4003. (University Microfilms No. 77-29,926, 1978).

On a personal computer (PC), the amount of information that can be stored is much smaller and so requires that students engage in frequent disk-switching. It is far less likely that a complete curriculum can be accommodated on a PC, and indeed, most software for PCs covers only small segments of instruction in a subject area. The student and teacher, however, have more flexibility in how the computer will be used.

Until recently, CAI programs were little more than computerized workbooks. Information was presented on the screen, students were asked to indicate a response, and their response was evaluated. If the student was correct, he or she moved on; if incorrect, similar additional problems were given until correct responses were elicited. Critics argue that the drill and practice tasks could be accomplished less expensively without computers and that this particular use of the computer promotes passivity on the part of the user.[119, 120, 121]

Advocates argue that many students who have not yet mastered their basic skills can benefit from drill and practice and that providing instruction on the computer adds an element of attraction that helps to motivate students. In addition, the teacher is then freed up to provide initial instruction and to work with individuals or small groups of children.

A trend in CAI is to give students more control over the learning process and to view learning as an experience wherein the student explores the subject area in question. Such recent programs are based on a more cognitive approach to designing instruction and involve quite precise and detailed analyses of the subject matter, of students' errors, and of the factors that result in successful learning. These more sophisticated attempts to design effective computer-based instruction will be discussed in the next section.

Research on CAI

Hundreds of studies have been conducted to determine the effectiveness of CAI. Several researchers have synthesized the results of individual studies conducted at various levels to see if the results hold up across studies. [122]

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119. S. Carlson and R. Silverman, "Microcomputers and Computer Assisted Instruction in Special Classrooms: Do We Need the Teacher?," Learning Disability Quarterly, vol. 9, No. 2, 1986, pp. 105-110.

120. J. Garson, "The Case Against Multiple Choice," in D.O. Harper and J. Stewart (eds.), Run: Computer Education (Monterey, CA: Brooks/Cole, 1983).

121. Sherry B. Turkel and D. M. Podell, "Computer-assisted Learning for Mildly Handicapped Students," Teaching Exceptional Children, vol. 16, No. 4, 1984, pp. 258-262.

122. James A. Kulik, et al., "Effectiveness of Computer-based College Teaching: A Meta-analysis of Findings," Review of Educational Research, vol. 50, 1980; see also J. Kulik, et al., "Effects of Computer-based Teaching on Secondary School Students," Journal of Educational Psychology, vol. 75, No. 1, 1983.

Results of these syntheses reveal that elementary level students who received brief daily CAI lessons as a supplement to instruction showed gains equivalent to one to eight months of instruction over their peers who received traditional instruction only.[123] However, when CAI is used as the sole basis for instruction, the results are mixed.

Other findings show that CAI is more effective at raising achievement among low-achieving students than for average or high-ability students, and that students complete material faster with CAI than with traditional instruction - sometimes as much as 40 percent faster. Increases in student attendance, motivation and attention span have also been reported in most studies. Students who learned on the computer remembered as much of the material as did students who received traditional instruction only.

Similar results were revealed in studies of CAI with secondary and college and adult populations. However, the gains in achievement were less significant.[124]

Disparity in Use. There appears to be a disparity in the types of students who use the computer for drill and practice and those who use the computer to study programming. Several researchers have noted that Chapter I and other low-ability students typically use the computer for drill and practice in basic skills, while gifted students typically use the computer to study programming.[125, 126] Moreover, in low-wealth schools, where students were predominantly white, students received five times more instruction in programming than did students in predominantly minority elementary schools.

This disparity can be defended in part, in that low-ability students are more likely to need the type of support provided by drill and practice. But while it may be true that low-ability students do need to master basic skills,

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123. James A. Kulik, et al., "Effectiveness of Computer-based Education in Elementary Schools," Computers in Human Behavior, vol. 1, 1985, pp. 59-74.

124. Dean Jamison, et al., "The Effectiveness of Alternative Instructional Media: A Survey," Review of Educational Research, vol. 44, No. 2, 1974, pp. 1-6; and D. N. Hansen, "Computer Assistance with the Educational Process," Review of Educational Research, vol. 36, 1966, pp. 588-603; also David B. Thomas, "The Effectiveness of Computer-assisted Instruction in Secondary Schools" AEDS Journal, vol. 12, No. 3,1979, pp. 103-115.

125. Henry J. Becker, School Uses of Microcomputers: Reports from a National Survey, Issues 1-6, (Baltimore, MD: Center for Social Organization of Schools, Johns Hopkins University, 1983- 1984).

126. Elizabeth Reisner, The Use of Computers in Instruction Supported Under Chapter I of the Education Consolidation and Improvement Act, (Wash, DC: Policy Studies Assoc., 1983).

they can also benefit from instruction that develops their higher cognitive abilities and learning strategies. Unfortunately, there is a tendency to consider such instruction beyond the ability of low-achieving students and to offer only gifted and high-achieving students such opportunities (with and without the computer).[127]

An exception is the HOTS (Higher Order Thinking Skills) Program developed by Pogrow at the University of Arizona. The program is designed to teach thinking skills to Chapter 1 students, primarily by teaching teachers to ask questions that elicit thinking responses. Teachers are also taught how to use selected software as the focus of socratic dialogues with students. Early results indicate that Chapter 1 students enrolled in the HOTS program showed substantially greater gains on standardized tests when compared with the national average. According to Pogrow, the HOTS program is the only National Diffusion Program aimed at Chapter 1 students that is designed to develop thinking abilities. Most programs focus on providing drill and practice in basic math and reading skills.[128]

Methodological Problems. Becker and Clark have identified a number of flaws in many of the earlier CAI studies. One problem, also found in many of the studies reported throughout this chapter, is that the computer treatments were supplementary while control treatments were not. For example, students using computers would receive 40 minutes per day in mathematics instruction, ten of which would be devoted to drill and practice on the computer. The control students would only receive 30 minutes of instruction. In this case, one cannot be sure that the increased performance of the treatment students was due to the extra ten minutes per day or to the drill and practice on the computer. Would the results be so significant if the control students received an extra ten minutes using flash cards or some other form of drill?[129]

In one study where the principal ensured that the control classes had a comparable 25 minutes of practice time using traditional workbooks, the control students outscored students in the computer-based treatment.[130]

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127. Beau F. Jones, "Quality and Equality Through Cognitive Instruction," Educational Leadership, April 1986, pp. 5-11.

128. Stanley Pogrow, "Preliminary Report on the Effectiveness of the HOTS Program," unpublished data, 1987.

129. Henry J. Becker, The Impact of Computer Use on Children's Learning: What Research Has Shown and What It Has Not (Baltimore, MD: Center for Social Organization of Schools, The Johns Hopkins University, 1987); and Richard E. Clark, "Evidence for Confounding in Computer-based Instruction Studies: Analyzing the Meta-analyses," Educational Communications and Technology Journal, vol. 33, 1985, pp. 249-262.

130. Patrick Suppes and Mona Morningstar, "Computer-assisted Instruction," Science, vol. 166, Oct. 17, 1969, pp. 343-350.

But Becker cites other findings in which there was no difference between 16 studies where the computer group received extra time and 12 studies where they did not.[131] Other methodological flaws cited by Becker include disproportionate attrition from experimental groups, non-random assignment of students to treatments, absence of comparable instructional content supplied to the students in the control groups, and a potential difference in the quality of teachers in computer and control groups. Clark suggests that the power of the effects would be reduced by 25% if only studies where the same teacher for both computer and control groups were considered. He stresses that the key influence on learning is not the computer, but the instructional method or event that is presented on the computer. A survey of several studies supports Clark's contention. Results showed that the effectiveness varied greatly depending upon the instruction presented on the computer.[132]

Becker reviewed the CAI studies conducted since 1984 using an approach called the "best-evidence synthesis". Both the best-evidence and meta-analytic approaches attempt to determine the effect of a particular treatment across groups of studies and both use an indicator of average effectiveness called "effect size." Effect size is based on the standard deviation unit and is an index that shows how much an experimental group outperformed the control group in a comparison study. The meta-analytic approach has been criticized because it fails to take into account the quality of the studies when averaging results. The best-evidence approach attempts to counteract these criticisms by attending more to studies with high-quality research designs.[133]

Using the best-evidence approach, Becker looked at computer-based studies using only micro- or mini-computers and addressing the basic curricular areas of math, language arts, writing, science, etc. Out of 51 research reports identified, 26 were excluded for one of the following reasons: no comparison group, no pre-tests, students not randomly assigned, duration too short, or insufficient numbers of students. Becker classified the remaining studies into clusters representing their degree of experimental quality and reported results according to these categories. Overall, the CAI results remain positive even after taking study quality into account.

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131. James A. Kulik, Chen-Lin Kulik and Robert Bangert-Drowns, "Effectiveness of Computer-based Education in Elementary Schools," Computers in Human Behavior, vol. 1, 1985, pp. 59-74.

132. Robert Bangert-Drowns, et al., "Effectiveness of Computer-based Education in Secondary Schools," Journal of Computer-based Instruction, 12, pp. 59-68.

133. Robert E. Slavin, "Best-evidence Synthesis: An Alternative to Meta-analytic and Traditional Reviews," Educational Researcher, vol. 14, No. 9, 1986, pp. 5-11.

A major limitation of this thirty-year body of research is that it provides virtually no insight into how CAI produced those learning outcomes. It is only recently that researchers have begun to ask more useful questions, such as how and what do students learn when they interact with computer-based instruction.[134] Becker is currently engaged in a national field study designed to provide important information about the features of various computer-based programs that influence learning. The study will have a large, representative sample, will occur over three years, will have appropriate experimental design, and will collect information on how the various programs are implemented in various grade levels and subjects. Each one-year study will involve 80 classrooms from across the country and will have matched control/treatment classrooms in the same schools. Specific implementations will be determined at the school and teacher level and will vary from site to site. The intent is to document the variations in conditions and characteristics of each implementation and to correlate these with the effects of each mini-experiment. Hopefully, the results of this controlled investigation will provide insight regarding the specific attributes of computer-based instruction that enhance or inhibit learning.

Cost Effectiveness. A final aspect of the CAI debate is how it compares on cost-effectiveness measures with other types of educational interventions. This issue is discussed more fully in another chapter, but one significant study is briefly described here.

Glass, Levin and Meister compared four types of intervention programs with regard to cost-effectiveness: CAI, cross-age tutoring, increased academic time and reduced class size.[135]

When the four interventions were compared on an effectiveness-only basis, cross-age tutoring was far superior to CAI in improving students' mathematics abilities and somewhat superior in improving their reading abilities. When costs were considered, cross-age tutoring, specifically peer tutoring, maintained an advantage over CAI, although to a somewhat lesser degree. These results suggest that, although the research findings regarding CAI are consistently positive, CAI may not be the most effective, nor cost-effective approach to improving student performance in basic skill areas.

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134. Biological Sciences Curriculum Study, Microcomputer Based Education: A Review with Emphasis on Elementary School Science Education, (The Colorado College, A Design Study of Elementary School Science and Health Education, December 1986).

135. Henry M. Levin, et al., Cost Effectiveness of Four Educational Interventions, Project Report No. 84- All, (Stanford, CA: Institute for Research on Educational Finance and Governance, Stanford University, 1984).

Intelligent Computer-Assisted Instruction

For over 30 years now, researchers have puzzled over ways to capture the unique potential of the computer so that it will behave more intelligently. This scientific domain, called artificial intelligence (AI), has captured the imagination and attention of researchers from a variety of fields, including developmental and cognitive psychology, linguistics, computer science, and others, in the pursuit of providing a machine with the intelligence of a human. The goal is to develop computer programs that model the knowledge of human experts in a particular domain.

Although scientists and pholosophers have been intrigued with the notion of simulating human intelligence for centuries, it is only as recently as the 1950s that sufficient computer power emerged to permit the simulation of human actions and thought processes. Early efforts focused on understanding and replicating the activities of the human brain through the study of neural networks. This was followed by the development of generative programs that produced from large data bases, a range of problems with which the student could work -- problems that were more suited to the individual student's level of skill. With the advent of faster computers in the 1970s, research expanded into the areas of voice recognition and speech synthesis and relies, in part, on understanding and processing natural language. It is just now that the benefits of the past 30 years of research in artificial intelligence is beginning to be considered useful and available to practitioners in business, medicine, and in education.[136]

Some Distinctions Between CAI and ICAI

Intelligent computer-assisted instruction (ICAI) is a branch of artificial intelligence devoted to developing instruction in curricular areas. The distinctions between CAI and ICAI are both subtle and profound. With CAI, instruction is controlled by the developer of the program who determines what is presented, how much information is presented, the order of presentation and the specific questions to which the student must respond. CAI programs cannot respond to students' questions, responses, or problems that are not specifically designated in advance by the programmer.

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136. James L. Poirot and Cathleen A. Norris, "Artificial Intelligence Applications in Education," The Computing Teacher, August/September, 1987, pp. 8-10. Much of the information in this section is drawn from a paper entitled, "Intelligent Computer-assisted Instruction: A Review and Assessment of ICAI Research and Its Potential for Education," by Christopher J. Dede, et al., (Newton, MA, Education Development Center) 1985.

ICAI programs are generally designed to increase students' control over the machine and to allow them the opportunity to "learn by doing". Students are able to interact with the computer rather than merely respond to it in a pre-specified way, and tutoring is often carried on in dialogue form, responding to student input. In addition, ICAI is characterized by a far more thorough and fine-grained analysis of the skills, knowledge and procedures involved in solving problems in a domain. The strength of ICAI is not only the substantially more precise and detailed understanding of the nature of learning and problem solving in a domain, but also the ability of the program to articulate, or make transparent that understanding in a form that can be absorbed by the student. ICAI programs specify in detail a mix of three types of knowledge: the declarative knowledge (what), the procedural knowledge (how), and the metacognitive knowledge (thinking about what and how).

ICAI, also referred to as intelligent tutoring systems, is comprised of four primary components: the first is a program that represents an expert's problem solving knowledge and behavior based on a detailed analysis of expert performance in the domain. Researchers actually sit down with an expert and observe and ask questions as the expert goes through the problem-solving process. The second component is a program of the typical errors a novice is likely to make, also based on observation and detailed analysis of student errors. The rationale is that errors are often systematic and that identifying and categorizing them can facilitate the correction of the misconceptions that cause the errors. Error-analysis programs are able to construct a detailed model of a student's knowledge in the subject in question.[137]

The third component of intelligent tutoring systems is the tutor that instructs, guides and corrects the student as he or she progresses through the program. Issues in the design of the tutoring component include: when to intervene, what to say, how to say it, and how much to say. For example, frequent interruptions may decrease students' initiative and motivation; explanations that are too detailed may bore students, and explanations that are too general may not adequately communicate the needed information. The fourth component, and the one that is most difficult to design, is that of communication, the way in which information is exchanged between student and computer. Efforts to communicate in the natural language that humans use involve expertise in semantics and syntax, as well as the more elusive aspects of communication, such as contextual knowledge of real-world phenomena and common sense about events and human interpretations of such events.

Intelligent tutoring systems (ITS) are able to generate and solve problems, store and retrieve data, diagnose students' misconceptions, select appropriate teaching strategies, and carry on dialogues with students. In addition,

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137. John Seely Brown and Richard R. Burton, "Diagnostic Models for Procedural Bugs in Basic Mathematical Skills," Cognitive Science, vol. 2, 1978, pp. 155-192.

they employ a wider variety of teaching strategies than are likely to be found in simple CAI programs. Many intelligent tutoring programs incorporate simulations and/or games that allow students the opportunity to "try out" their evolving models of knowledge in a domain.

For example, Quest is an intelligent tutoring system in which students acquire increasingly sophisticated models of electric circuit behavior through exposure to a sequence of carefully selected circuit problems. Quest contains simulation activities that allow students the flexibility of solving problems in a variety of ways, as well as allowing them to design an arbitrary circuit of their own that they can test through the simulation. This is possible because all of the formal electrical laws of circuitry are built into the program and used to determine whether or not a student's circuit works.[138]

Students can also receive a step by step, voice-simulated explanation of the way in which an expert would solve a problem, complete with the reasoning that underlies each step of the solution. The Quest system can explain the differences between the students' present model and the correct model, and can turn problems into examples or use examples as problems.

The Quest learning environment provides students with the opportunity to select from among several instructional approaches. For example, the open-ended exploration option lets students construct and modify circuits, and test them with the simulation to see how they work. With the problem-driven learning option, the system presents a series of problems for students to solve and gives computer-generated voice explanations of the solution when requested by the student. In example-driven learning, the system tutors the student on problem solving strategies and gives computer-generated voice explanations of the solution. Student-directed learning allows the student to decide which problems to solve and which learning strategy to use.

Quest is based on extensive cognitive research conducted to identify the essential knowledge about electric circuits and the optimal way to teach that knowledge. The researchers empirically analyzed what must be learned and devoted several years to experimenting with instructional approaches. As of Fall 1986, seven students have worked with the complete Quest program, and after five hours of "play", all of the students were able to answer simple questions about circuits and could troubleshoot for opens and shorts to ground in series circuits.

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138. Barbara Y. White and J. R. Frederiksen, "Intelligent Tutoring Systems Based Upon Qualitative Model Evolutions," in Proceedings of AAAI-86: The National Conference on Artificial Intelligence, Philadelphia, PA: 1986; and Progressions of Qualitative Models as Foundation for Intelligent Learning Environments, Report No. 6277, (Cambridge, MA: BBN Laboratories Inc., 1986).

Learning Through Reflection

Developers of intelligent tutoring systems have integrated several unique features into the systems that capitalize on what researchers have come to understand about how novices learn and how experts solve problems. These features are important because they represent the cutting edge of our understanding of teaching and learning, and because most have implications for other areas of computer and non-computer instruction. One such feature found in some programs is the audit trail. Audit trails leave a record of a student's work as he or she progresses through problem solving. This record, or trail, allows students to look back over their own or other students' work and to reflect on the relative value of various approaches to problem solving. (Figure 6 is a picture of an audit trail left by a student engaged in solving geometry proofs in an intelligent tutoring program called The Geometry Tutor.)[139]

Learning from our mistakes is an efficient way to learn. It takes advantage of what we already know and modifies it until we get it right. Less able students often view mistakes with despair. They throw up their hands and turn away. Good students view mistakes as an opportunity to learn -- to improve. Brown discusses the value of looking back over our work. "Only when we review various problem-solving paths, do we have an opportunity to understand why one line of reasoning or approach to the problem is more effective than another. This kind of . . . learning is one of the skills that characterize successful, lifelong learners" (p. 108).[140]

Imagine the conversation that might ensue as students analyze each others' audit trails left as they attempted to solve an algebra problem. "How did you get it to work in two ways?" "Why did you cancel out those terms?" "Oh! I see now! I should have simplified first." Through such dialogues, students can add strategies and interpretations to their repertoire without relying solely on the teacher or the textbook. They see that they can be a resource to each other and to themselves in solving problems.

Using audit trails, teachers can easily turn an exercise that might otherwise be considered "copying" into a mind-expanding lesson with a simple, "Look at each other's work and decide which approach is most elegant." "How many ways are there to solve this problem?" "Create a similar problem for your partner to solve." "What would make this problem just slightly more difficult without changing the numbers?" "Why?"

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139. John R. Anderson, et al., The Geometry Tutor (Pittsburgh, PA: Carnegie-Mellon University, Advanced Computer Tutoring Project, 1985); and C. F. Boyle, "The Geometry Tutoring Project in Action," Educational Leadership, March 1986; also Boyle and Anderson, Acquisition and Automated Instruction of Geometry Proof Skills, Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, 1984.

140. John Seely Brown, "Idea Amplifiers - New Kinds of Electronic Learning Environments," Educational Horizons, Spring 1985, pp. 108-112.

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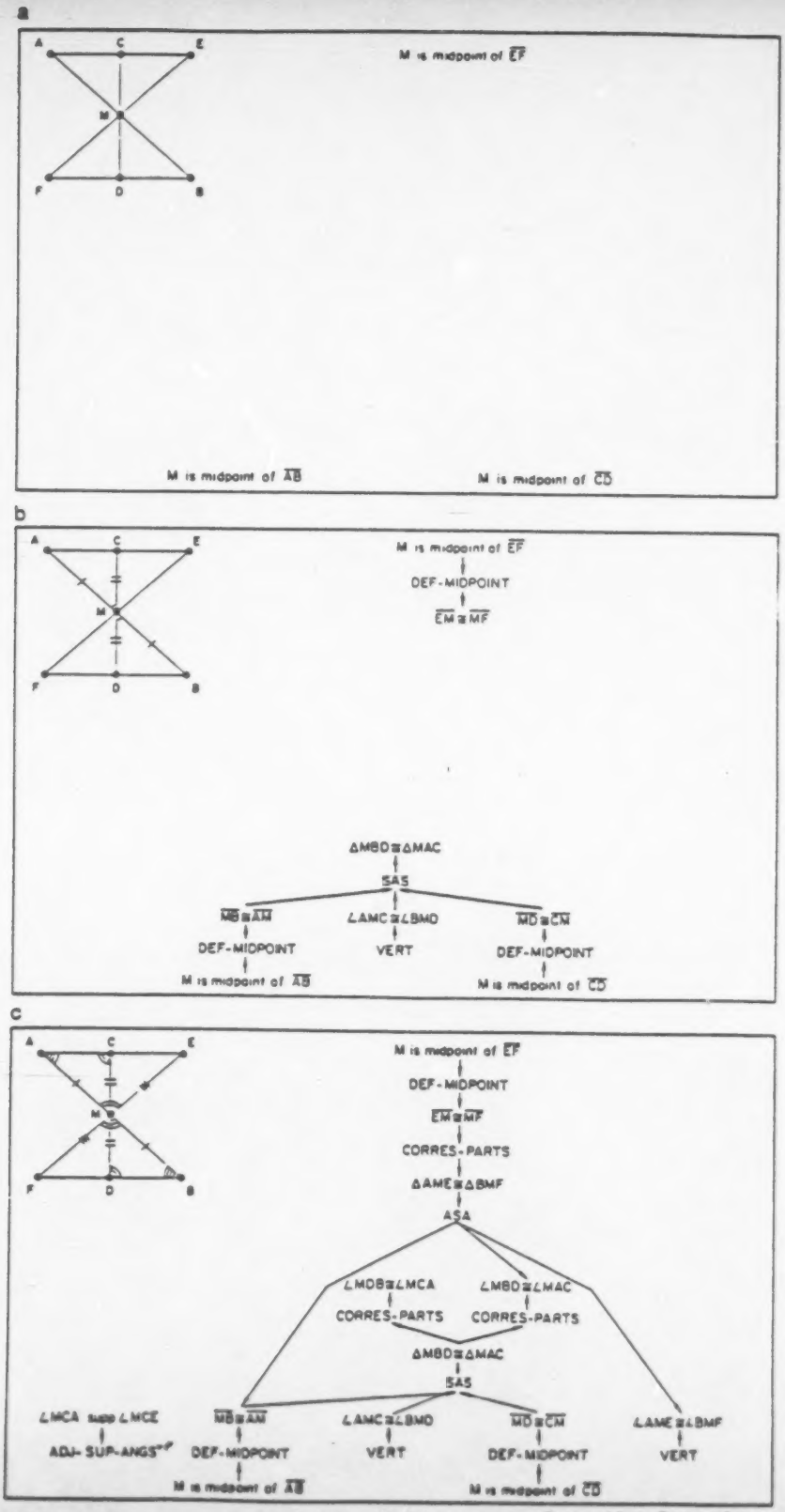

Figure 6: Sequential screens from the Geometry Tutor showing audit trail reflecting students' progress through the problem.

The Geometry Tutor is an intelligent tutoring system that employs audit trails and is currently under study at Carnegie Mellon University's Advanced Computer Tutoring Project. It provides instruction in geometry theorem proving and focuses on teaching students to problem solve and to plan when they prove theorems. According to the authors of the Geometry Tutor, these skills are seldom emphasized in a standard geometry curriculum. Students often complete a geometry course with only a modest ability to generate proofs and little deep understanding of the nature of proofs. The Geometry Tutor monitors students while they are actually engaged in solving the problems and provides instruction and guidance during the problem solving process. To receive feedback, students don't have to wait until their papers are corrected and the teacher shows the correct way to perform the proof. Feedback is immediate, precise, instructionally relevant and based on a far more thorough analysis of problem solving behavior than would be possible with one teacher and a classroom full of students.

Boyle, the Geometry Project leader, describes the tutor in action in a high school classroom:

> At any time in the process, the student can ask the system for help with definitions, postulates, and theorems appropriate to the problem. In addition, if the student is not on a proof path, the tutoring part of the system (that is, that part that keeps track of the student's strategic choices) will guide the student back onto a proof path. Should the student make a logical error in inference, the system recognizes the error and tutors accordingly. The system functions as coach or as tutor, depending on need. (p. 27).

Anderson and Boyle's approach to developing an intelligent tutor has been to derive principles of effective tutoring from theories of instruction rather than to imitate the behavior of a human tutor. As the student progresses through a proof, the computer identifies the differences between the student's model and the ideal model and provides instruction in the differences. The system is guided by eight instructional principles:

> 1) Problem solving involves decomposing major goals into subgoals.
> 2) Learning is more effective if it takes place in a problem solving context.
> 3) Immediate feedback prevents students from wasting time pursuing incorrect strategies.
> 4) Students can be more effective at problem solving if they do not have to remember every step of the solution process. (The tutor provides a memory aid by use of windows that display rules and definitions.)

The Geometry Tutor was initially tested on a few high school students, some who had no geometry instruction and some who had just completed a high school geometry course. After ten hours of instruction, all students were able to solve problems that their teachers considered too difficult to assign to their classes. In fact, a student who had almost failed geometry was successful, and the students considered their time on the computer as "fun." The researchers are now testing the Geometry Tutor in a high school comparing the treatment students' performance with that of a control group of students.

Because intelligent tutoring systems have primarily been developed for research purposes and because they require larger, more powerful memories than the computers typically found in schools, they are not yet available in classrooms, except on a research basis. However, the developers of The Geometry Tutor have recently managed to adapt their system so that it could be used on a Macintosh computer. This is a major step forward in making intelligent tutoring systems available to the general education audience.

The Challenge of Natural Language

Other intelligent tutoring systems have been developed in a variety of areas. For example, SOPHIE (SOPHisticated Instructional Environment)[141] provides students with an environment for learning how to solve problems by trying out their ideas within the context of a simulated electronics lab. The system can answer students' questions, critique their hypotheses regarding why a piece of circuitry equipment is not working, and suggest alternative explanations.

SOPHIE's ability to communicate with students depends on its natural language capabilities. The process of programming a computer to understand the ambiguities of natural language is one of the most intractable problems confronting AI researchers today. SOPHIE's developers have addressed the issue of natural language by replacing conventional categories of grammar, such as nouns and verbs, with categories that represent concepts relevant to the SOPHIE system, such as circuit, transistor, or hypothesis. The system then attends only to the concepts it recognizes and tries to make sense of students' responses from those concepts, ignoring other pieces of information.

Representing aspects of natural language communication, such as context or physiological cues, is a very difficult problem, and may significantly limit the types of instruction that a computerized tutor can present. There is not yet agreement among the AI and linguistics research communities as to whether the problems associated with communicating in natural language can be solved.

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141. John Seely Brown, Richard R. Burton, and J. de Kleer, "Pedagogical, Natural Language, and Knowledge Engineering Techniques in SOPHIE I, II, and III. In D. Sleeman and J. S. Brown (Eds.), Intelligent Tutoring Systems., (London: Academic Press, 1982).

Other intelligent tutoring systems address instruction in diverse areas including: South American geography (SCHOLAR), causes of rainfall (WHY), medical diagnosis (GUIDON), arithmetic (WEST), and computer programming (LISP). [142]

Summary. Intelligent tutoring systems are particularly interesting and promising for two reasons: one is that they are being developed by researchers who have devoted a great deal of time to the study of how people think, learn and solve problems, and thus offer a deeper and more accurate understanding of how the mind works. Many believe that the field of artificial intelligence offers the greatest promise to the improvement of teaching and learning.

Second is the ability to provide individualized coaching that might not otherwise be feasible. Clearly, a machine will never surpass the quality of instruction provided by a good teacher working with a student in a one-to-one setting. But most teachers work with classes of 20 to 30 students and seldom are able to spend more than a few minutes with any one student. Intelligent tutoring systems can provide students with responses that are tailored to their individual needs and are based on the knowledge and strategies used by experts. If a student does not understand a skill or concept, then he or she may practice exercises incorrectly. Or if a student knows the component parts of a complex skill but has not mastered putting them together, the intelligent tutoring system can offer assistance in integrating the skills. Such expert and individual assistance is currently available only through the most highly qualified and able teachers, particularly in the more technical areas of mathematics and science where shortages of qualified teachers are a problem.

At the present time, intelligent tutoring systems are not yet functional for use in the classroom (with the possible exception of The Geometry Tutor). Because most systems were developed for the purpose of tackling a specific component of intelligent tutoring (e.g., expert knowledge, student errors, tutoring, or natural language), they are often incomplete. To produce complete systems will require a substantial investment of money, time and expertise.

In addition, it is not yet clear how much of the research and development conducted on one application will apply to other applications. So far, it appears that intelligent tutoring systems are domain-specific and are best suited to domains that can be well-defined and are not too complex, such as in the domains currently under development (e.g., fractions, physics, and organic chemistry).

The need to articulate every detail of the tutoring process is providing a far deeper level of understanding of subject matter, of learning, of teaching, and of the process of natural language, an understanding that can ultimately benefit teaching and learning in schools.

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142. A. Stevens, et al., "Misconceptions in Students' Understanding," in Derek Sleeman and John S. Brown (Eds.), Intelligent Tutoring Systems, (London: Academic Press, 1982); J. W. Wallis and E. H. Shortliffe, "Explanatory Power for Medical Expert Systems: Studies in the Representation of Causal Relationships for Clinical Consultations," Methods of Information in Medicine, vol. 21, 1982, pp. 127-136; R. R. Burton and J.S. Brown, "An Investigation of Computer Coaching for Informatl Learning Activities" in Derek Sleeman and J.S. Brown (Eds.), Intelligent Tutoring Systems (London: Academic Press, 1982); John R. Anderson, et al., "Learning to Program in LISP", Cognitive Science, vol. 8, 1984, pp. 87-129.

Research on Teachers Using Technology

> "Learning to use computers as educational tools [is] a very complex task, perhaps more complex than is normally associated with inservice training. This is significant because program developers and policy makers may make erroneous decisions if they underestimate the complexity of the training teachers need to use computers effectively" (p. 2).

This is the conclusion of authors of a recent nationwide survey of teachers and computer coordinators, and supports the anecdotal reports of many of the researchers and developers described in this review of computer reearch.[143]

In many of the studies reviewed, researchers reported that they had underestimated the amount of time and training that teachers needed to feel comfortable and adept with computers. This was particularly true when the computer was intended to be used as a tool for inquiry. Teachers have historically found inquiry-based teaching strategies difficult. Inquiry strategies involve dialogues that center around observations of the world. Questions, predictions, observations, and generalizations are all essential aspects of successful inquiry learning. It requires that teachers find the proper balance between structure and open-ended discussion and exploration.

In their survey of teachers, Stecher and Solorzano identified ten factors that seem to be important for effective computer inservice programs: 1) extensive use of computers, 2) careful balance between lecture and guided practice, 3) the provision of lesson-related materials and handouts to facilitate the learning of commands and procedures, 4) individual attention to teachers' questions, 5) relating lessons directly to classroom curriculum, 6) peer interaction, 7) voluntary participation and, 8) the use of knowledgeable trainers. The survey respondents reported that 9) organized support and 10) encouragement at the school and district level are essential keys to success.

Survey respondents reported that lack of access to computers in their home schools and limited association between the content of inservice classes and the curriculum they were responsible for teaching, were factors that hindered teachers' classroom use of the knowledge and skills learned in the inservice. Winkler, Stasz and Shavelson also found that teachers were far more likely to engage in inservice computer training if computers were made available to them. They found that this was the single most influential factor in increasing teacher participation in training.[144]

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143. Brian Stecher and R. Solorzano, Characteristics of Effective Computer In-service Programs (Pasadena, CA: Educational Testing Service, 1987).

144. John D. Winkler, et al., Administrative Policies for Increasing the Use of Microcomputers in Instruction" (Santa Monica, CA: The Rand Corporation, 1986).

Survey respondents commented on the difficulty in balancing the design of in-service sessions that focused on clearly defined goals and objectives, while maintaining flexibility as computers evolve and new instructional uses emerge. Stecher and Solorzano stress that is important to put the history of computer training in perspective, and remind us of the dramatic but steady change in the ways computers are being used in education. In the beginning, almost all computer use consisted of drill and practice and programming. Then computer literacy entered the scene, adding historical and ethical dimensions to the picture. Educators are now directing their energies to exploring ways to use tool applications, such as data bases and electronic networks, and to assist learning in the content areas. Stecher and Solorzano characterize the second half of the 1980s as the era of "curriculum integration" in computer education.

One trainer they interviewed described the situation at his school after three years of training teachers: "We are still at the pilot stage. We try it out, see what works and what does not. Two years from now we will think about bringing it all together." (p. 44).

It is important that policy makers understand that these changes in direction are not the result of indecision or lack of planning. Computers and other forms of technology are opening new vistas never before imagined and changes in direction should be viewed as essential steps needed for an enlightened use of technology.

Teachers Need Time

A recent evaluation report of a genetics simulation illustrates the importance of time and training needed to learn to integrate computers into the curriculum. Three high school teachers volunteered to try out a biology simulation program and participated in an all-day workshop to help prepare them for using the materials. The workshop consisted of a demonstration of a computer-based genetics experiment, followed by three hours of time for teachers to work individually at the computer going through the remaining six experiments. They then reconvened as a group to discuss the printed materials that included the computer directions, student worksheets and lab report sheets, the purpose of the experiment and background information.

At first glance, one would think that this would be sufficient preparation for the teachers to feel comfortable using the materials. Not so. The teachers with the most teaching experience (15 years) were the least comfortable using the computer. According to the evaluators' description of one of these teachers, "He seemed afraid that students would not pay attention if they had to observe someone else run the computer rather than having a hands-on experience with the computer themselves. Also not having confidence in using a computer and the fear of embarrassing himself in front of his students affected his decision to incorporate computers into his own lessons" (p. 20).

The teacher with only two years teaching experience but with a familiarity with computers, ". . . possessed the greatest ease with computers [and] was the most comfortable integrating the computer into his class instruction. For example, he used the computer to run an experiment where students had obtained inconsistent data. This teacher was also skilled at maintaining the students' attention while he operated the computer. He constantly monitored what he was doing on the computer, always involving the students in answering questions." (p. 20).

All three of the teachers reported that preparing to use the materials required a significant investment of their time, and none had had time to read over the printed materials or run the experiment before using it with their classes.

Coaching and Assistance

Research in staff development has shown that training that merely introduces or models the desired teacher strategies is insufficient to change teacher behavior in the classroom. To achieve real change requires that teachers practice and receive feedback on the new skills or strategies while in the training session, as well as in-classroom observation and coaching by the individual providing the training or someone who has been trained to observe and coach -- a cycle that may need to be repeated several times.[145] While this approach to staff development is obviously more costly, it may be the only way to ensure that the desired changes occur.

Winkler, et al., found that teachers were more likely to use computers if technical assistance was provided. The most useful form of assistance was help in integrating computers into instruction. Integration assistance requires the routine availability of a knowledgeable person "to help teachers decide the optimal ways to deliver computer-based instruction to students, to link the computer activities with ongoing instruction, and to coordinate those activities with other classroom activities" (p. 42). It was the least common form of support found in the districts surveyed.

Summary. Although some researchers have begun to explore ways to assist teachers in using technology in the classroom, many questions remain unanswered. There is little information about how these applications fit with the existing curriculum, how the existing curriculum may need to be modified, or which parts of the curriculum should be changed or deleted altogether.

The limited research available on teachers' use of computers indicates that integrating computers into the classroom is more difficult and complex than anticipated, especially when accompanied with inquiry-based teaching strategies. Teaching in an inquiry mode suggests a view of teaching and learning that departs substantially from common practice. Indeed, there are many dimensions of the current system of schooling that work against a teacher's efforts to develop students' reasoning abilities (e.g. standardized tests, time pressures, and discipline, etc.). All this suggests that successfully integrating computers into the classroom is a challenge that encompasses multiple dimensions of the educational process.

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145. Bruce Joyce and Beverly Showers, "The Coaching of Teaching," Educational Leadership, vol. 44, No. 1, 1982, pp. 4-10.

What is clear, is that closure or resolution is elusive. There will need to be a considerable investment of time, money and energy on the part of educators and policy makers at all levels before we can reap the full benefits of computers in the classroom.

CONCLUSION

The ways in which computers are being used in classrooms is changing dramatically. Educators are moving away from using the computer as the object of instruction (e.g., computer literacy and programming) to using it as a tool for intellectual work. The uses as a tool are quite numerous and exploration into their potential is just beginning.

The research that has been conducted to date is spread across a range of uses, settings, subjects and types of students. Although the findings are not conclusive in all cases, they are very encouraging. Some of the more promising computer uses derive from research on how people think, learn and solve problems. This body of research, coupled with the potential of the computer to free students from some of the lower-level and tedious thinking tasks (e.g., plotting a graph, recopying an essay), arm educators with two new powerful tools to activate deep and meaningful student learning.

There are several things that are clear, even from the limited information now available: 1) the issues involved are complex and intertwined. It is almost impossible to look at one piece of the effectiveness-of-computer puzzle by itself -- each piece is dependent upon, or affects, another; 2) one of the most critical factors in the success of computers in the classroom is the teacher. If teachers do not have sufficient time, training, flexibility and support to learn how to integrate technology so that it suits their needs and those of their students, we can never expect to reap the full benefits that technology has to offer; 3) recent research in cognitive science and in other areas of education are beginning to provide a new view of the way that children become better thinkers, learners and problem solvers. Both traditional and technology-based instruction should take advantage of these increasingly valuable research findings; 4) we need to think beyond ways to use technology to teach our current curriculum -- and think, instead, of how the current curriculum should be restructured.

RECOMMENDATIONS

1. Clearly, research and development efforts should continue to be funded and, in fact, funding levels should be increased. Academic researchers, and district staff involved in research and evaluation at the local level, all lamented the limited research dollars available. Indeed, according to a recent study by the General Accounting Office, federal funds for research in education have declined by 70 percent in constant dollars from 1972 to 1986.

Major areas of study should include: how to help teachers thoughtfully integrate technology into the classroom, how the curriculum will need to be restructured to promote deep-level learning, and in what ways do specific computer applications or tools enhance and provide students cognitive engagement with learning. Other important questions include: what sorts of support structures need to be in place (e.g., technical support, training support, materials support)? What changes in the curriculum are needed when students learn some topics substantially faster with the computer?

Also needed is further research to expand the range of computer applications. For example, data based management systems seem to have endless potential for use in many subject areas. Intelligent tutoring systems offer tremendous promise for understanding learning and problem solving as well as for providing comprehensive instruction in selected areas. Significant effort and fiscal resources should be devoted to extending this research and to disseminating the fruits of the research and development work to practicing educators.

There was almost no research available on the use of computers with bilingual students. Special efforts should be made to fund research in this area.

2. Collaborative research should be encouraged. Practitioners can be vital to expanding the base of information on computers in the classroom. Teachers involved in such collaborations have been enthusiastic, and researchers repeatedly extol the contributions afforded by eliciting teachers' views. Moreover, teachers who are involved in inquiry are more likely to encourage inquiry in their classrooms. Support should include funds to carry out the research, and release time for teachers to engage in planning, design, training, data analysis and interpretation, and revision of materials.

3. Temporarily relax accountability when a new use of the computer is being introduced. Teachers need to feel free -- even encouraged -- to experiment. The pressure of accountability for student performance may inhibit teachers' willingness to experiment. This does not mean that tests shouldn't be given: they can provide useful information in assessing the value of a particular computer application. But teachers may feel pressured to address goals that may be at least temporarily incompatible with computer exploration.

For example, learning to incorporate MBLs or data base programs requires a considerable amount of trial and error on the part of both teachers and students. Both need to learn how to operate the technology, to master inquiry-based teaching and learning strategies, and to learn specific content. Each step should be mastered before attempting to determine whether the technology is a more efficient tool for teaching and learning than a non-technology-based approach.

4. Further research and development in the assessment of higher-level thinking skills should be supported. Many tests assess facts, rules and procedures but are not adequate measures of deep-level understanding of complex concepts, or of students' ability to generalize what they've learned to solving real-world problems.

Many of the applications discussed here are intended to promote deeper levels of understanding, but evidence regarding the effectiveness of such applications is limited by inadequate testing technology.

Another concern is that many of the learning outcomes attributed to computers are not content based. Rather, researchers and teachers are seeing social outcomes (student cooperation in learning, increased motivation to come to school, increased motivation to pay attention) and self-regulation outcomes (e.g., students accepting more responsibility for their own learning or using strategies for managing their learning). These are important outcomes that should also be considered when assessing the value of computers in schooling.

5. Students learning to be teachers should receive training in how to use the most promising applications of technology in the classroom. By incorporating instruction in the use of technology into methods courses, student teachers will more clearly see how to integrate technology into the curriculum. Such training should be accompanied by research-based strategies for teaching thinking and problem solving. Both elementary teachers and secondary teachers should master inquiry-based teaching strategies during their preservice training.

Teachers should be also receiving training in other strategies for developing students' thinking and problem solving abilities. A great deal of new research is emerging in this area and should be integrated into computer-training efforts. This means that teachers are learning in two conceptually demanding areas. It means that they will often be required to substantially restructure their instructional strategies, focus, and materials. This requires time -- time to learn how the technology works, to "play around" with it, and to explore the variety of ways it can be used to teach different topics. If teachers are uncertain, they are likely to rely on the more familiar teaching strategies that are useful in conveying facts and procedures but less effective for communicating complex concepts and processes.

In general, teachers typically receive time to attend training. They seldom, however, receive paid time to restructure their teaching, their curriculum, their thinking. There is no evidence to tell us what happens when teachers do have time to reflect. But, it's an important question that should be studied. It may be the difference between patchwork reform and substantive reform.

6. Teachers currently on the job will continue to need training. Learning one application of the computer does not ensure mastery of another. Moreover, the possible uses of computers for learning will continue to grow over the next few years, resulting in a need for increased efforts in teacher training, not a decline. Shortages of funds for training and for release time are a constant problem for many school districts.

7. Continue providing funds for the purchase of computers in schools. Many colleges and universities require that every student own a computer. As the range of in-classroom computer applications expands, it is easy to see that students could productively use the computer for a major portion of their school day. Whether or not this will necessitate a computer for every student is unclear, but the few settings

where this is being explored should provide useful information in the near future.

8. Fund efforts to disseminate information and training on the more promising computer applications, as well as the results of research in computer use. For many of the applications described in this chapter, there are literally thousands of educators who have no idea the application even exists, much less how it would be useful to them.

9. Concerns over equity have focused on equality of access to computers, resulting in many instances where poor and low-achieving students get to use computers as frequently as do high-ability students and those from wealthier schools. But in many situations, there is no consideration of the inequities of what is learned from the differential uses of computers. Educators and policy makers must ensure that all students receive encouragement, support and opportunities to develop the higher order thinking abilities that will enable them to apply technology to the solution of problems.

Conclusion

Although there is not yet sufficient evidence to allow unrestrained endorsement of the computer applications reported in this chapter, almost all of the findings were to some degree positive. Moreover, a number of the applications described were designed on a sound theoretical basis. The developers were familiar with and incorporated research on learning. In one way or another, all software or applications were designed to make complex concepts more accessible to students, or to assist students in mastering basic skills so that they could then focus more attention on conceptually demanding aspects of learning. Because not all software is so thoughtfully conceived, the systematic study of computer use in learning must continue.